REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
31-Jul-2013	FINAL Report	Mar 2012 - July 2013

4. TITLE AND SUBTITLE

High Productivity Aluminum Manufacturing Final Phase I Report

5a. CONTRACT NUMBER
N00014-14-D-0377

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

NSAM
Alcoa

5d. PROJECT NUMBER
S2404

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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8. PERFORMING ORGANIZATION REPORT NUMBER

S2404 Deliverable #10

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research (Code 03TMT)
One Liberty Center
875 N. Randolph Street, Suite 1425
Arlington, VA 22203-1995

10. SPONSOR/MONITOR'S ACRONYM(S)

ONR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Distribution A. Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Present practices for aluminum butt welding on LCS consist of labor-intensive and relatively costly procedures. Multiple weld passes are used to complete an aluminum weld. Besides requiring a high level of labor, multiple welding passes can result in extra weld induced distortion of weldments that requires rework. Aluminum panels and modules currently require welding from both sides. For panel line welding, this necessitates a multi-step procedure. This project's objective was to improve the current time-consuming and labor-intensive welding procedure by developing a mechanized welding method capable of single-sided, single-pass (SSSP) aluminum butt welding. Preliminary estimates of the cost savings potential of SSSP welding were in the range of 30 to 35% for every dollar currently spent on conventional aluminum flat down-hand butt welding.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Kevin Carpentier
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (include area code)
Unclassified	Unclassified	Unclassified	SAR	142	843.760.4364

HIGH PRODUCTIVITY ALUMINUM MANUFACTURING

Final Phase 1 Report
for Period March 2012 – July 2013

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July 2013

CNST Base Task Order Agreement Number 2012-440

DISTRIBUTION STATEMENT A. Approved for public release.

PREPARED FOR:
CNST
5300 International Boulevard
Charleston, SC 29418
843-760-3200

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)* 31-07-2013	**2. REPORT TYPE** Phase 1 Summary	**3. DATES COVERED** *(From - To)* March 2012 to July 2013

4. TITLE AND SUBTITLE CNST – High Productivity Aluminum Manufacturing Final Phase 1 Report and Appendices One Through Four	**5a. CONTRACT NUMBER** 2012-440 **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHOR(S) Philip Gacka, William H. Grassel, Israel Stol, Kyle L. Williams, Daniel M. Myers, Kirit Shah, D. J. Spinella	**5d. PROJECT NUMBER** **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Alcoa, Inc. 100 Technical Drive Alcoa Center, PA 15069	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) SCRA Applied R&D 5300 International Boulevard Charleston, SC 29418	**10. SPONSOR/MONITOR'S ACRONYM(S)** **11. SPONSOR/MONITOR'S REPORT NO's.**

12. DISTRIBUTION / AVAILABILITY STATEMENT

DISTRIBUTION STATEMENT A. Approved for public release.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This report documents the first year of a two year program to develop single side, single pass butt welding capability of aluminum 5083 marine plate used for LCS construction. Welding process parameters and equipment techniques were developed to successfully weld 5/16" (8mm) thick plate. Technical limitations of this process made it unlikely it would be implemented in LCS shipyards. It was recommended not to continue this program to the planned second year, Phase 2 tasks.

15. SUBJECT TERMS

butt welding, LCS, high deposition, GMAW, HDGMAW, aluminum 5083

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT Unclassified	**b. ABSTRACT** Unclassified	**c. THIS PAGE** Unclassified	UU		W. Southerland **19b. TELEPHONE No.** 843-760-3482

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

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1.0 Executive Summary

The ManTech High Productivity Aluminum Manufacturing program activity started in March 2012 per SCRA Base Task Order Agreement 2012-440. Under the direction of CNST, Alcoa Defense, Inc. (ADI) and its shipyard partners, Austal and Marinette, began a two year effort to develop and demonstrate a High-Deposition Gas Metal Arc (HDGMA) aluminum welding system. The goal was to enable single-sided, single-pass (SSSP) butt welding of select aluminum plate structures for both LCS classes of ships, Independence and Freedom. This two year program was broken into two phases with each phase being about 12 months in duration.

ADI's HDGMA aluminum welding system has the following innovations & benefits:

- Reduces multiple weld passes to a single pass (saves labor) and increases productivity;
- Eliminates the need for back-gouging (saves labor);
- Increases mechanization of welding operations, resulting in more consistent welds and fewer repairs (less rework);
- Reduces total welding heat input per linear length, thereby decreasing weld-induced distortion and rework (less rework time & materials);
- Reduces consumption of welding filler wire (material savings);

ADI's HDGMA aluminum welding process has the following implications, limitations and additional requirements compared to the Gas Metal Arc Welding (GMAW) process currently being used by shipyards.

- The maximum combined gap & vertical mismatch that will reliably produce a sound weld is 1.5mm gap, & 1.0mm vertical mismatch (increases labor for fit-up and/or eliminates some welds as candidates for HDGMAW);
- The process requires a bevel as part of the weld preparation for welding all thicknesses, to enable tactile seam tracking and to maintain the proper weld top (i.e. on face side) reinforcement height. Current shipyard practice typically does not require bevels on thinner material (increases labor);
- The process requires the use of a temporary backing bar to be placed-on the root side of joints to be welded to contain the root reinforcement and to allow for gas venting. This is an additional requirement, as compared to the Baseline GMAW processes used by the shipyards who were partners in this project.
- The edges of the root reinforcement must be ground to meet the re-entrant angle requirement for visual inspection (increases labor);

The cost saving target for HDGMAW was in the range of 30 to 35% savings for every dollar currently spent on aluminum plate butt welding in the flat down-hand position. A cost model was completed in Phase 1 to update the savings potential based on the factors listed above.

Phase 1, completed in July 2013, resulted in the development of procedures for flat down-hand welding of 5/16" thick (8mm nominal) 5083-H116 marine plate. Evaluation of horizontal out-of-position (OOP) HDGMAW welding was also done in Phase 1.

Toward the end of Phase 1, the state of HDGMAW technology development was reevaluated with respect to its expected readiness for implementation at the end of Phase 2. CNST determined that projected cost saving no longer justified continued process development. Three specific factors contributing to this assessment were:

1. Restrictive fit-up requirements between parts to be welded
2. The need for temporary back-up bars to be inserted beneath the weld seam
3. Backside weld grinding required to guarantee desired root weld reentry angle

ONR’s Program Officer for CNST agreed with this assessment. This program was terminated after a modified Phase 1 task list was completed.

2.0 Program Goals and Objectives

Present practices for aluminum butt welding on LCS consist of labor-intensive and relatively costly procedures. Multiple weld passes are used to complete an aluminum weld. Besides requiring a high level of labor, multiple welding passes can result in extra weld induced distortion of weldments that requires rework. Aluminum panels and modules currently require welding from both sides. For panel line welding, this necessitates a multi-step procedure that includes:

- Preparing plate edges to be welded;
- Clamping and fixturing panels;
- Welding the joint through part of the thickness from one side with several weld passes;
- Flipping the panel assembly and re-clamping;
- Back gouging welds to prepare the weld areas on the side to be welded; and
- Welding the remainder of the joint from side two with several weld passes.

The differences between conventional and high deposition GMAW process are illustrated in Figures 1a and b.

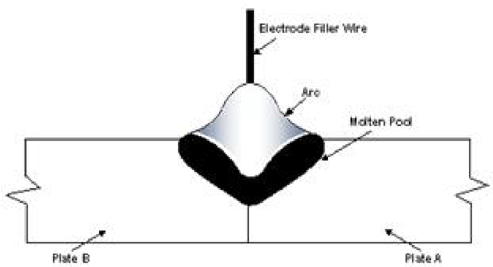

Figure 1A – Conventional GMAW

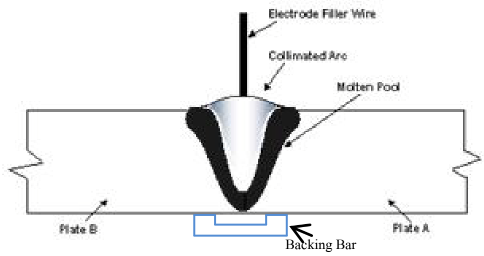

Figure 1B – High Deposition GMAW

This project's objective was to improve the current time-consuming and labor-intensive welding procedure by developing a mechanized welding method capable of single-sided, single-pass (SSSP) aluminum butt welding. Preliminary estimates of the cost savings potential of SSSP welding were in the range of 30 to 35% for every dollar currently spent on conventional aluminum flat down-hand butt welding. The Phase 1 cost model showed the potential savings for flat down-had (FDH) butt welding to be 21% for a total of $5300 in the case studied which had a total of 560 feet (170m) FDH welding. This savings estimate is affected by the assumption of the additional labor to meet the maximum gap and vertical mismatch limits for the HDGMAW process. ADI has made an estimate of this additional labor as being 1.5X that of the Baseline GMAW. This assumption should be refined by shipyard operating data. ADI did a sensitivity analysis to determine the breakeven point as a function of this additional labor. For the thickness considered in the cost model, the HDGMAW process would be the same overall cost if the multiplier was 2.6X. Also, due to the gap and vertical mismatch limitations, some welds may not be feasible with HDGMAW because the gap and vertical mismatch cannot be met regardless of the labor applied. It is not possible for ADI to estimate this, but, it has been cited as a concern by both Austal & Marinette Shipyards.

<u>3.0 Program Team</u>

SCRA Applied R&D is the Contractor for ManTech Task Order 2012-440. Under SCRA's management, the entities contributing to this program and specific areas of accountability are listed below.

Alcoa Defense, Inc. (ADI) provides technical leadership in the development of the equipment, processes, and procedures required for single side, single pass welding of aluminum marine plate. This includes experimental work to define specific welding parameters, selection of welding equipment, and preliminary cost saving assessments with respect to conventional GMAW practices. ADI works with LCS shipyard team members to obtain data needed to document current GMAW construction methods and data to compare with the new HDGMAW process.

Austal USA and Marinette Marine Corporation shipyard personnel monitor and contribute to the development of the HDGMAW system to ensure that its features are compatible with shipyard use. As requested by ADI, general shipyard welding practices, data, and weld samples are provided for comparison with HDGMAW.

American Bureau of Shipping (ABS) supports ADI by establishing and assessing weld quality targets the HDGMAW process must meet.

PMS 501 and NAVSEA 05 Navy personnel monitor all program developments, ensuring HDGMAW welds meet the Navy's technical requirements and economic expectations.

Personnel associated with the Phase 1 portion of this program are listed in Appendix 1.

4.0 Target Setting for Technical Development of Single Side, Single Pass Welding

4.1 Selection of Materials and Welding Parameters for Program Process Development

The official HPAM program kick-off meeting was held at the Alcoa Technical Center on March 27, 2012. One of the first program activities was to establish specific parameters Alcoa would use for initial HDGMAW process development.

During separate meetings with shipyard personnel in April, parameters for eleven different aspects of the HDGMAW system were determined. These system features described in Appendix 2 defined the initial parameters used for HDGMAW system development.

4.2 Configuration of HDGMAW System at ATC: Equipment Gap Analysis

Alcoa has done HDGMAW welding of various aluminum alloys and metal thicknesses over the past 10 years. This knowledge was applied to the current marine plate butt welding program to determine what equipment and ancillary materials would be required for process development.

Appendix 3 summarizes the resulting Gap Analysis. Alcoa equipment available for this program was identified in addition to equipment and materials that needed to be purchased or fabricated.

4.3 Welding Process Quality Specification

Appendix 4 contains metrics to assess welds produced by the high deposition GMAW process. These metrics were developed to provide a quantitative standard that HDGMAW joints would need to meet for use in production. These quality metrics were shared with the entire HPAM team in a meeting on May 31, 2012 and distributed by email on June 11, 2012. The email requested input from all team members. The Phase 1 Go-NoGo Checklist was distributed on September 27, 2012 and October 8, 2012. This checklist has a detailed listing of quality requirements from the specification. It was reviewed and presented as complete in the 2012 3rd Quarter Project Review Meeting and Minutes. The only reply received from the team on this topic was from NAVSEA on July 2, 2012. This reply specified that NAVSEA considered this a new welding process and required additional testing beyond those required for weld qualification. This email is included in Appendix 4. Reports for these tests are in Section 5.10 (Testing of HDGMAW for Acceptance as a New Weld Process).

5.0 HDGMAW Welding Parameters Development

5.1 Shielding Gas Selection and Qualification

Alcoa used an inert gas mixture of helium and argon as the shielding gas in past HDGMAW development. This prior work showed the benefits of the hotter, collimated arc obtained when using helium as a component of the shielding gas. Because of these past Alcoa welding experiences, the HPAM program started with a shielding gas composition of 75% He/25% Ar, with the full agreement of all the members of this program.

During the second quarter program review, representatives from Austal and Marinette expressed concern with including helium in the shielding gas composition. Helium was currently used for some welding at Austal, but helium was supplied on an allocation basis due to its limited availability. Marinette did not use any helium containing welding gas; all welding was done with 100% argon.

Alcoa agreed to determine if the HDGMAW process was viable with 100% argon shielding gas. Planned process development work was put on hold and all resources were allocated and directed toward assessing the potential of using only argon as the shielding gas with this welding technique.

Appendix 5 contains test data obtained using the HDGMAW process with shielding gas compositions of:

- 75% Helium / 25% Argon
- 25% Helium / 75% Argon
- 100% Argon

These data were reviewed during an entire program team meeting on August 07, 2012. There were obvious differences in weld cross-section using the three different shielding gas mixtures. However, each shielding gas produced welds with acceptable quality or with attributes that could be controlled by adjusting other process parameters. The team decided to continue process development with 100% argon shielding gas. Notes from this meeting are also included in Appendix 5.

5.2 Temporary Backing Bar Geometry and Plate Edge Preparation Determination

Because HDGMAW is used by welding from one side of joints, a temporary backing bar is used to support and contain the molten pool at the back side (i.e. root) of butt joints, until it solidifies. A recess in the backing bar is aligned with the weld seam. This recess helps to shape the solidifying metal. After a weld is completed, temporary backing bars are removed and cleaned for reuse or discarded.

Backing bars can be made from a variety of materials. The main technical requirement for a temporary backing bar is the capability to support and contain the molten pool of aluminum without fusing to the weld and becoming a part of it. Other considerations for the backing bar include the capability of effectively venting the pressure that builds up in its recess, the cost, the capability to be placed along the weld seam, and ease of removal after the weld is made.

A comparison of backing bar recess geometry was made to determine what to use for HDGMAW development. Appendix 6 compares the performance of ceramic backing bars with radii in the recess and anodized aluminum backing bars with rectangular recesses.

In these trials, neither backing bar geometry was capable of consistently shaping the root side of the weld, so it always meets the targeted root reentrant angle of greater than 90°. Any gap between the backing bar and the root side of the abutting parts resulted in a re-entrant angle of less than 90° on that side of the root reinforcement. For the backing bars with radii in their recesses and recesses that were either too shallow and/or too narrow, pressure build-up within these recesses was thought to contribute to the variability in weld geometry. To achieve the specified reentrant angle of greater than 90^0 at the back side of the welds, Alcoa recommended to grind the roots of the welds, regardless to whether they were produced with a radiused or non-radiused recesses in the backing bar. Backside weld grinding would be expected to be a manual operation along the entire length of the weld. This step was added to the cost model for the HDGMAW process. See the detailed cost model report in Section 5.11 for the cost contribution for this operation.

Recess depth in the Temporary Backing Bar as well as the bevel machined at the top edges of the butt joints were also found to affect the geometry of the weld root and height of the weld reinforcement, at the top (or face) side of the welds. Appendix 7 presents additional data from the welding evaluations used for selection of the top bevels and recess geometry for welding with the HDGMAW technique.

5.3 Establishing Parameters for the Baseline Welding Condition

Initial HDGMAW welding trials conducted with 5/16” (8mm) thick 5083-H116 plates, from April through September 2012, were used to determine welding process parameters to be used for systematic process development. Data from Appendices 6, 7, and 8 were the basis of a project review with all team members on October 04, 2012. Option 1 in Appendix 8 was selected for development of Baseline HDGMAW process parameters. The baseline was defined as butt welds with zero gap and zero vertical mismatch between plates. The baseline welding parameters are shown in Appendix 9. The welding system used for these trials is described in Table 1.

Table 1 – Lincoln GMA System

1. Lincoln Power Wave 455M Power Supply (program 40 Power Mode)
2. Lincoln Power Feed 25M Wire Feeder
3. MK Products Python Push Pull Welding Gun

5.4 Achieving Joint Gap and Vertical Mismatch Plate Position Goals

After developing the Baseline HDGMAW process parameters for butt welds with no joint gap or vertical mismatch between plates, the next program step was to determine whether the targeted combination of 0.060” (1.5mm) gap and 0.060” (1.5mm) vertical mismatch could be achieved per point 7 in Appendix 2.

Figure 2 shows that the baseline welding parameters (Appendix 9) were inadequate for accommodating the targeted variation in joint fit-up. As can be seen from Figure 2, joints with zero gap could be welded-with acceptable welds with an vertical mismatch of up to 0.1” (2.5mm). However, the largest plate gap that could be accommodated was 0.020” (0.5mm) at zero vertical mismatch. This limited gap accommodating capability was insufficient to meet the weld quality needs in the shipyard welding environment. As a result, Alcoa halted further process development with the initial baseline parameters and explored options to increase the joint gap accommodating-capability with the HDGMA welding technique.

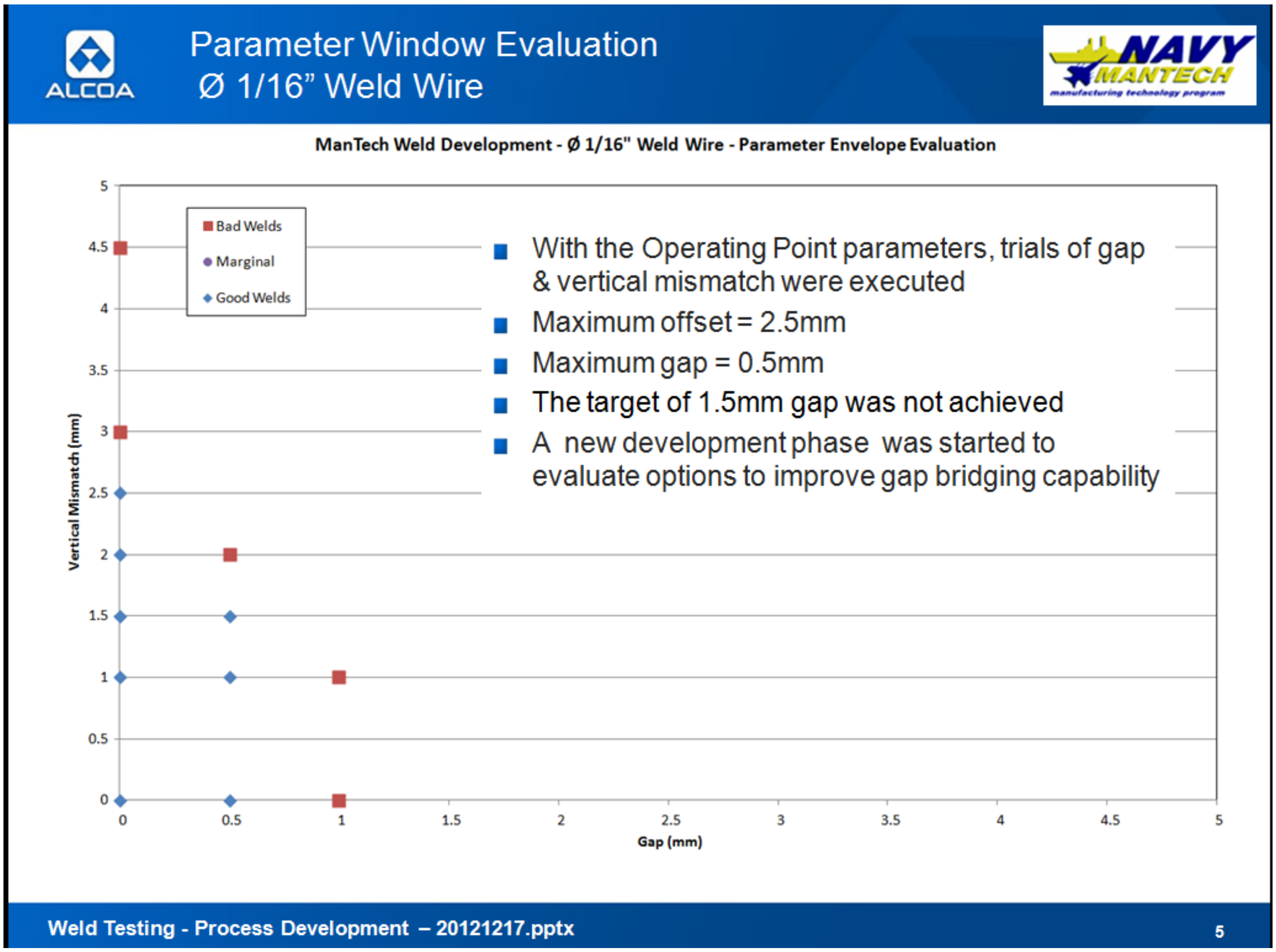

Figure 2 – Performance of Baseline HDGMAW With Plate Gaps and Vertical Mismatch

Ideas generated by Alcoa to increase the gap welding distance are shown in Appendix 10. The ideas are force ranked according to likelihood of success, where the first technique is the most “promising” and most likely to provide the sought after welding capabilities (i.e. increased forgiveness to variations in joint gaps and/or parts vertical mismatch) and the eighth one is the least likely to do so. These techniques were screened by rating them according to a visual examination of weld quality. Results are shown in Table 2.

Table 2 – Final Ranking of Methods to Increase HDGMAW Joint Gap & Vertical Mismatch Welding Capability

Final Rank	Option	Result	Implication
1	Larger Diameter Electrode - Weld wire was increased from 1/16" (1.59mm) to 3/32" (2.38mm)	Good Weld	Change power supply, weld wire less common, more heat input
2	Develop parameters to accommodate 2mm gap with current joint design - proove feasibility of Adaptive Fill Control	Good Weld	Requires laser seam tracker & complicated control system implemenation
3	Offset Torch Lateral Position - constant	Good Weld	Implementation complexity, unsure of effectiveness with veritcal mismatch
4	Change weld prep, Reduce Amps & Travel Speed (possible nominal gap)	Good Weld	Requires laser seam tracker & complicated control system implemenation
5	Square Butt, 1mm TBB Groove, 100% Argon	Marginal Weld	
6	Change weld prep - Single Bevel	Marginal Weld	
7	Reduce TBB Groove Depth - Single Vee 2mm Depth of Prep.	Bad Weld	
8	Back Hand Torch Angle - constant	Bad Weld	

Increasing welding wire diameter from 1/16" (1.59mm) to 3/32" (2.38mm) was found to be the most effective approach for better accommodating larger joint gaps and higher vertical mismatch between the parts. To weld with this larger diameter [i.e. 3/32" (2.38mm)] welding filler wire, the welding system was switched from the Lincoln system (Table 1) to the ESAB Welding system described in Table 3. The switch was necessary because the wire feeder of the Lincoln system was not capable of using 3/32" (2.38mm) weld wire. The ESAB welding system (Table 3) was used for Flat Down Hand welding development from this point on in the program.

Table 3 – ESAB GMA System

1. ESAB 652 CVCC Power Supply (CC Mode)
2. ESAB MIG 35 Wire Feeder
3. L-TEC ST-21 Push Welding Gun

To experimentally verify that welding with the larger 3/32" (2.38mm) diameter welding wire made the HDGMAW process more forgiving to joint gaps and vertical mismatch between parts, the 1/16" (1.59mm) diameter wire was also run with the ESAB 652 welding system. The results of welding with the 1/16 (1.59mm) diameter wire reconfirmed that welding with the 3/32" (2.38mm) diameter wire made the HDGMA welding process more forgiving to joint gaps and vertical mismatch between parts up to 0.080" (2mm).

The aforementioned results were shared with the entire project team on December 18, 2012. During this program review, five major open issues with welding with the 3/32" (2.38mm) diameter welding wire using the ESAB welding system were identified. These issues included:

- The transverse (to the weld) Ultimate Tensile & Yield Strengths and % Elongation (i.e. TYE) of the weldments produced with the 3/32" (2.38mm) diameter wire may be lower than the strengths of weldments produced with the original 1/16" (1.59mm) diameter wire, using the Lincoln welding system.
- The feasibility & ease of welding out of position with the HDGMAW technique may be affected. This concern stemmed from the fact that welding with the larger diameter 3/32"

(2.38mm) welding wire, would involve a larger molten pool, whose shape and movement may be adversely affected by gravity.

- The use of a 3/32” (2.38mm) diameter welding wire, which is commercially available, but less commonly used.
- Power Supply
    - The ESAB 652 CV/CC Power Supply is an older system and is not commercially available.
    - It will be necessary to program the waveform & speed of response on a current model to match the behavior of the ESAB 652 CV/CC.
- Wire Feeders
    - This availability of wire feeders 3/32” (2.38mm) wire that are compatible with the selected power supply will need to be investigated.

Austal and Marinette shipyard team members agreed that 3/32” (2.38mm) wire would be acceptable to use in production. The decision was made to resume Phase 1 of the HDGMAW development program using the 3/32” (2.38mm) diameter wire and the ESAB welding system.

5.5 Determination of Centriod, Final Parameters and Maximum Gap & Vertical Mismatch

Once the decision was made to use the 3/32” (2.38mm) diameter wire and the ESAB welding system, welding trials to determine welding parameters capable of accommodating larger joint gaps and vertical mismatch between parts and performance of the welds, were renewed. These welding trials started with the use of a temporary Backing Bar recess depth of 0.070” (1.78mm).

These welding trials revealed an improved tolerance to joint gaps up to 0.080” (2.0mm). However, the welding Parameter Operating Window was shown to be narrow, with the current operating range of 355±5 amps. Refer to Appendix 11 Figure A11-3 for the Parametric Envelope plot. Due to the depth of the 0.070” (1.78mm) recess in the backing bar, at the wider joint gaps the top weld reinforcement tended to sag and become concave and more difficult to control.

Based on these results, the recess depth was reduced to 0.050” (1.27mm) and Parameter Operating Window was again investigated. The shallower recess depth limited the tendency of the welds’ top reinforcement to sag and become concave, when welding larger joint gaps. With this recess depth in the Backing Bar, there was a significant improvement in the tolerance to 0.080” (2mm) gaps. This also widened the range of welding current/welding speed of travel combinations that could be used for producing sound and dimensionally acceptable welds with up to 0.080” (2mm) joint gaps. In addition, this shallower recess depth afforded the welding of up to 2mm vertical mismatch between parts, at 0mm joint gaps. Refer to the Parametric Envelope plot presented in Appendix 11 Figure A11-11.

Using the backing bar with the 0.050” (1.27mm) deep recess, HDGMA welding trials were carried out with different joint gap/vertical mismatch of parts combinations. The results from these trials showed that:

- Welding parts with 0.080” (2mm) Gap & 0.080” (2mm) Vertical Mismatch was not feasible.
- Welding parts with 0.080” (2mm) Gap & 0.060” (1.5mm) Vertical Mismatch was not

feasible.

- Welding parts with 0.060” (1.5mm) Gap & 0.060” (1.5mm) Vertical Mismatch resulted in inconsistent weld quality. Out of 16 welding trials, 6 welds were of unacceptable quality, 5 of marginal quality and 5 were of acceptable quality.
- Welding parts with 0.060” (1.5mm) Gap & 0.040” (1.0mm) Vertical Mismatch yielded welds with consistently acceptable weld quality and geometry. This joint gap & vertical mismatch combination became the maximums for welding these joints with the HDGMAW process.

The aforementioned details were presented at the team meeting on February 22, 2013, during which the concept was demonstrated by welding two 5 feet long pairs of plates. Appendix 11 presents the full report given at that meeting describing developmental activities and testing used to determine the acceptable parametric operating envelope. The welding system, equipment and welding conditions chosen to demonstrate the HDGMAW technique are shown in Tables 4 and 5, respectively.

Table 4 – Welding system and equipment used for welding with the 3/32” (2.38mm) diameter wire

- Power Source: ESAB 652 CV/CC
- Wire Feeder: MIG 35
- Torch/Gun: ST-21 – Push
- Backing: Type – Temporary – Rectangular Recess – 1.3mm (0.05”) x 25.4mm (1.0”), Material - Anodized Aluminum
- Gullco Model # GK-200-RHB Kat Track Weld Carriage and Track
- Gullco Electronic Seam Tracker
- Current Type: Constant Current (CC)

Table 5 – Final set of welding conditions chosen for demonstration of the HDGMAW technique with the 3/32" (2.38mm) diameter welding wire, using the welding system and equipment listed in Table 4

- Current Type: Constant Current (CC)
- Current-Polarity: DC-EP
- Average Amperage: 369 Amp
- Average Voltage: 31.0 Volt
- Travel Speed: 22.9 IPM
- Number of Weld Passes: 1
- Weld Position: Flat Down-Hand (1G)
- Electrode / Filler: Alloy – ER5183, Diameter – 0.093 in. (2.4mm)
- Shielding Gas: Argon, Flow Rate: 50 SCFH
- Preheat Temperature: Room Temperature
- Torch Angle: Work Angle: 0.0, Lead Angle: 15 degrees
- Weld Preparation: 90^0 included angle & 0.080" (2mm) deep Vee groove top preparation
- Joint and Root Gap, below the Vee groove top preparation: 0

The Weld Procedure Specification (WPS) and Weld Procedure Qualification Record (WPQR) for flat down hand welding are presented in Appendix 12. In summary, all required non-destructive and destructive tests met their respective requirements except:

- Ultimate Tensile Stress did not meet the 40 ksi (275.8 MPA) limit. Two of the four required specimens were at 39.9 ksi (275.1 MPA) vs. the 40 ksi (275.8 MPA) limit.
- The root reinforcement requires post weld grinding to meet the > 90 degree reentrant angle requirement.
- The Top (Face) Weld Reinforcement meets the 0.090" (2.29mm) limit, but, was border line.

5.6 Weld Seam Tracking Method Assessment

The HDGMAW technique would be implemented in production through the use of a mechanized system, which consists of a track that translates the welding torch along the joints being welded and a mechanical seam tracking device, attached to the welding head (i.e. torch and its brackets) (Figure 3). This tracking system continuously locates the torch so that the tip of the welding wire and the arc at the required lateral position relative to the joint. To accommodate the stylus of this tracking system (Figures 8 & 10), the original Square-Butt joint in this program was modified to include a 0.080" (2mm) deep top Vee groove preparation with a 90° included angle (Appendix 12) in which it "rides" during the welding operation. The other purpose of this top Vee preparation is to help control the height of the top weld reinforcement.

During the initial development of HDGMA welding parameters in Phase I of this program, Alcoa used the Gullco KAT® rigid track and its torch holding & translating carriage system shown in Figure 3 and referenced in Table 4. Carriage motion in the X direction follows the general direction of the weld seam. To keep the proper position of the welding torch relative to the joints during welding, this system arrangement necessitated manual adjustments to the

position of the welding torch in the Y and Z directions. Part of Phase 1 of this program was to identify an inexpensive, effective and relatively simple seam tracking system for weld production with the HDGMAW technique, which will continuously and simultaneously maintain the required position of the torch relative to the joints, in the Y (lateral) and Z (Vertical) directions, dispensing with the need for frequent manual adjustments by the welding operator.

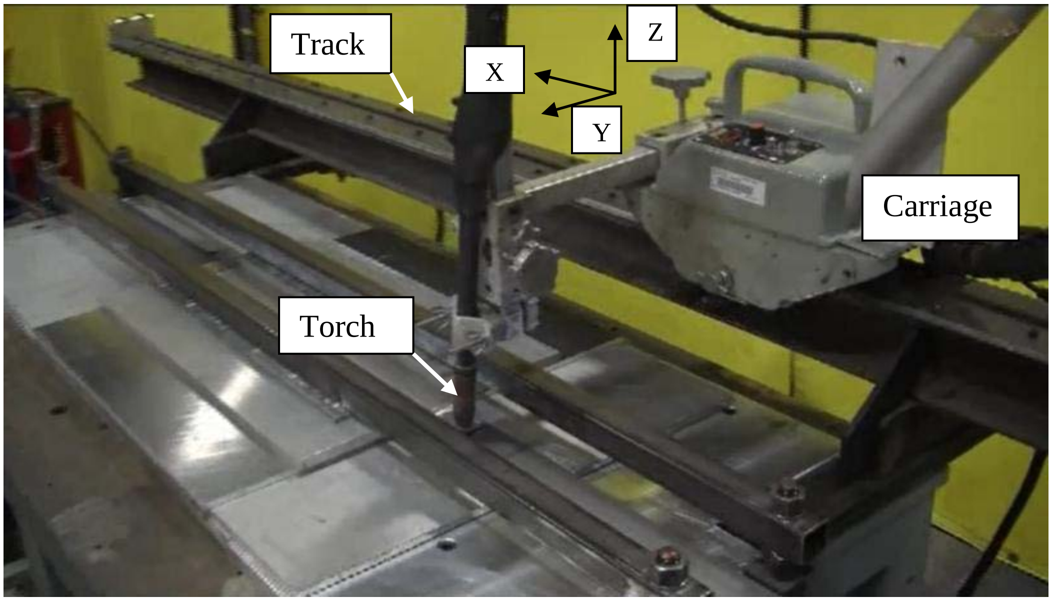

Figure 3 – Mechanized Gullco System Used for HDGMAW Process Development

Commercial seam tracking systems are either laser or tactile probe based. A comparison of the general characteristics of each seam sensing method is made in Table 6.

Table 6 – Seam Tracking Methods Comparison

Feature/Issues	**Laser Vision Seam Tracking**	**Mechanical Probe – Tactile Seam Tracking**
Welding Processes	Applicable to all arc and laser welding processes	Only works with relatively slow (less than 100ipm) fusion based welding processes
Material Type & Condition	Works on any material	Works on any material, although deep gouges, cuts and scratches at the tops of the joints being welded and/or oversized and/or excessively long [e.g. 5” (125mm)] tack welds and/or weld repairs, could compromise tracking effectiveness
Joint Types	Works on any joint type	Only works on tee fillet, lap fillet, groove. Cannot accommodate tight, square butt joints
Installation	Easy to connect and incorporate into the welding head and electrical system	Easy to incorporate into the welding head
Other Equipment Required	None	None

Table 6 – Seam Tracking Methods Comparison (cont'd)

Feature/Issues	Laser Vision Seam Tracking	Mechanical Probe – Tactile Seam Tracking
Search time	Can search for the joint quickly before tracking commences	The stylus must be engaged into the groove by the operator using manual position adjustments prior to initiating the weld process
Repeatability	Laser accurate to microns. Can be programmed to compensate for look-ahead distance	Probe is accurate to millimeters. Cannot compensate for look-ahead distance, i.e. as probe moves so does the welding wire
Material Thickness Limitations	Can go down to 0.020" (0.5mm)	For most joints like butt and lap fillet joints the thickness must be greater than 0.060" (1.5mm)
Flexibility	Can track faster than the welding process and can incorporate weaving if needed	Cannot always track faster than the welding process and cannot handle weaving requirements
Maintainability	Easy to maintain. Its main consumable is the protective lens.	Needs to replace probe as it wears or breaks during collisions
Adaptive Processing	Can measure gap and other joint features which can be used to modify welding parameters in real time. Cannot offset wire precisely.	Cannot measure gap or any joint features
Access	Laser line can be placed at optimum location relative to the torch.	Probe can be placed at optimum location relative to the torch.
Complexity to Learn and Use	A trained engineer or technician is required to select the signal processing filters and parameters and control algorithm parameters. Recommended training is a two day class. Troubleshooting in the field will require a trained engineer and may require technical assistance from the manufacturer.	System is simple to use. Hands on training takes 1-2 hours. The system can be brought on line within 4 hours.
Ability to work when tack welds are used to hold plates	Signal processing and control techniques are available to account for and accommodate tack welds. Control algorithms are very comprehensive for tack weld avoidance.	A simple control algorithm is available to suspend (i.e. skip or fly-blind) tracking when a tack weld is encountered. There are limits to the size of tack welds based on travel speed.
Typical Cost – sensor, servo-motor system, controller, recommended options	$104K	$15K

Even though all seam tracking requirements with the HDGMAW technique could be met with the laser or tactile based systems, the significantly lower cost of the tactile system led to its

selection for this phase of the program. Appendices 13 and 14 summarize the capabilities of the Gullco and Servo-Robots' tracking systems.

5.8 Proof of Concept Demonstration of the HDGMA Welding Technique

A major Phase 1 milestone was to weld 5/16" (8mm) thick, 5' (1524mm) long 5083-H116 plates in the flat down hand position, while using the Gullco seam tracking system (Figures 8 and 10) selected in this program. The demonstration took place during a visit by the HPAM program team to the Alcoa Technical Center on February 26, 2013. Figures 4 through 10 present images from a video of the same process.

The first step in the welding process is to prepare the plates. Following the grinding of the top (i.e. side of the top weld reinforcement) edge-bevels (Appendix 12), the edges to be welded and 0.5" (13mm) wide bands on their adjacent parent metals at the top and back surfaces were solvent cleaned, dried, abraded with a rotary hand held stainless steel brush and cleaned (Figure 4).

Figure 4 – Solvent Cleaning and Wire Brush Abrading of Plate Edges

Once the edges of the plates are prepared, they are tack welded together at ~20" (500mm) intervals, starting with tacks at the two ends of the joint, to which removable (or temporary) Run-In and Run-Off tabs are welded. The purpose of these tabs is to help control the quality of the welds at the start and ends of the joints, by starting the welding outside the joint and thus stabilizing the process before welding of the actual joint commences and terminating the weld outside it. To ensure un-interrupted tracking with the tactile sensor, as its probe (or stylus) is "sensing" the location of the joint, ahead of the torch & welding region (i.e. arc and molten pool), the tack welds and Run In and Run Off tabs are grooved in-line with the top Vee preparation of the joint, with the aid of a hand held grinder. Figure 5 illustrates these steps.

Figure 5 – Tack Welded Plates and Run In and Run Off tabs, grooved with the aid of a hand held grinder

Once the tack- welded and grooved flat plate assembly is completed, it is placed over the 0.050" (1.27mm) deep recess of the anodized welding backing bar (Appendix 12), which sits on top of the welding table, so the joint to be welded is approximately aligned with the centerline of the backing bar's recess. Aluminum backer plates placed next to the backing bar, support the back sides of the plates to be welded, so the tack welded assembly is nearly parallel to the welding table (Figure 6). The assembly is then secured and held in place with the aid of cambered (i.e. curved) steel clamps (Figures 7B, 8 and 9) and is ready for welding.

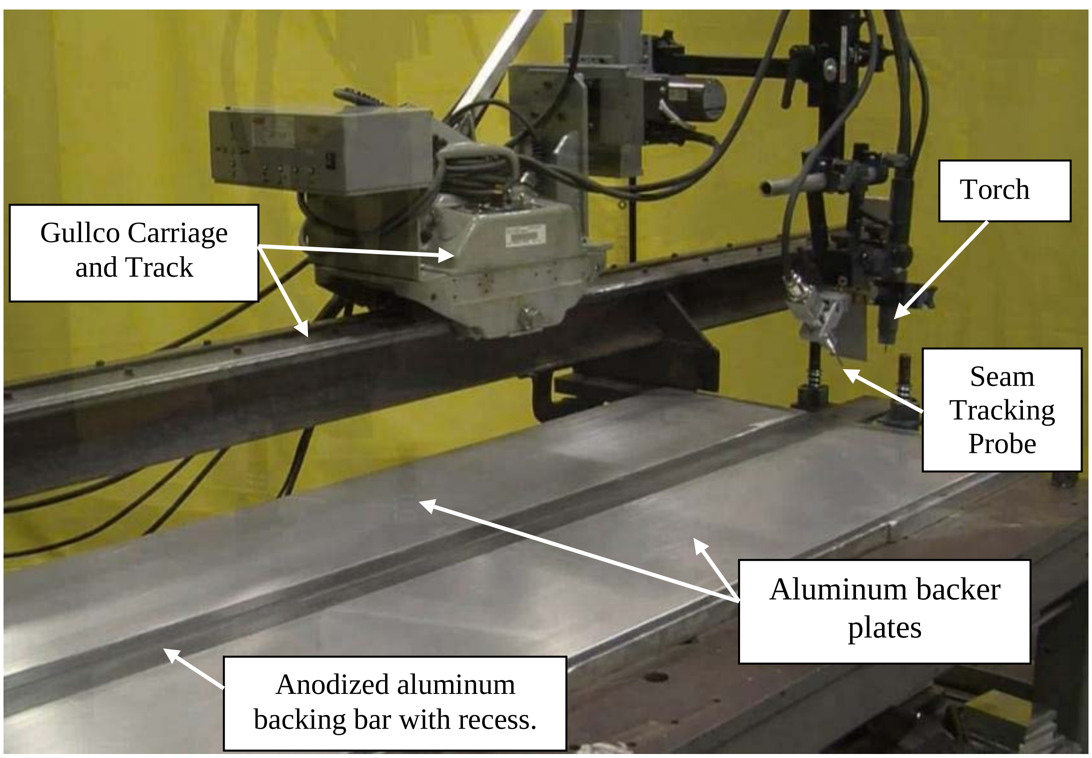

Figure 6 – HDGMA Welding Station at ATC, prior to placement and clamping of the tack welded assembly.

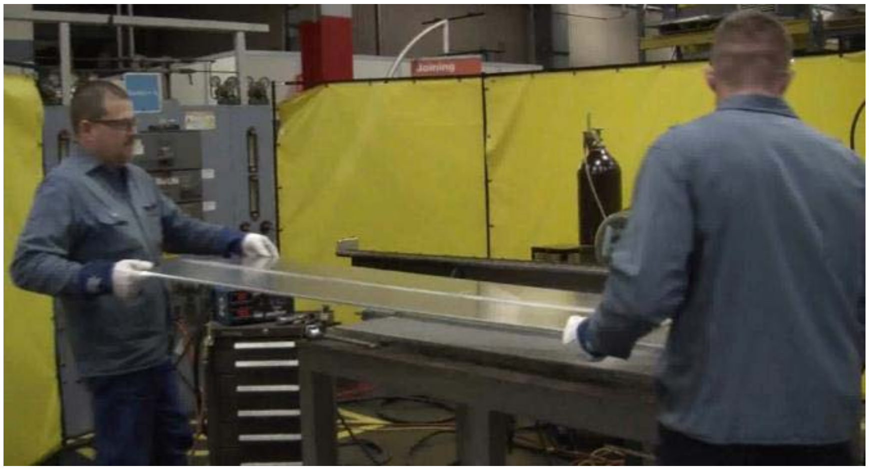

Figure 7A – Plate placement of the tack welded plate assembly onto the welding table over the recessed welding backing bar (not seen) and spacer plates (Figure 8).

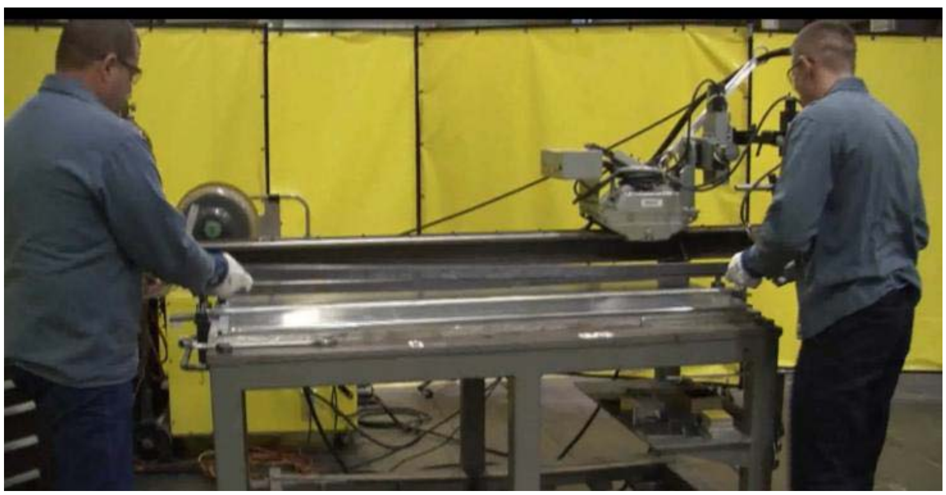

Figure 7B – Placement of the Cambered (Curved) Steel bar over the top of one of the two plates to be welded.

Once the tack welded assembly is placed and clamped in place, the torch and seam tracking system are lowered over and into the top bevel of the joint (Figure 8). To protect the seam tracking system (i.e. top sensor and stylus) from weld spatter and minimize its (i.e. spatter) landing in the joint's top bevel, a spatter/radiation shield is placed between the welding torch and tracker. The torch is positioned over the run-on tab ready for welding to begin.

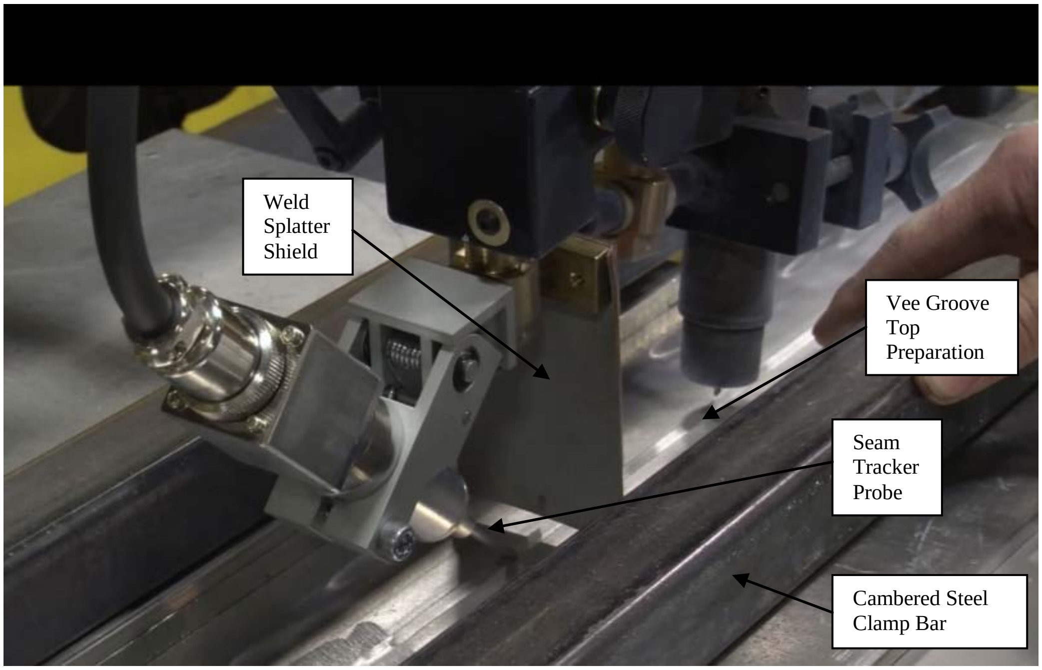

Figure 8 – Torch and Seam Tracking Probe Engaged in Weld Seam

Figure 9 shows the weldment with its top weld in the as-welded condition (i.e. not brushed) and after brushing the smut off it. Tables 4 and 5 respectively present the welding equipment and welding conditions used for producing this demonstration weldment.

Figure 9 – As Welded (left) and Brushed HDGMAW Welded Plates.

Properties of the weld are then evaluated as part of this program. Figure 10 shows the height measurement of the top weld bead.

Figure 10 – Height Measurement of the top weld bead, produced with the HDGMAW technique, with the aid of a dial gauge

5.8 Weld Evaluations and Testing

The conformance of the HDGMA welds in the proof of concept 5' (1524mm) weldments to the requirements specified in Appendix 2, included:

- Visual inspections of the top weld bead and back (root) bead
- Dye penetrant inspections of the top weld bead and back (root) bead
- Radiography
- Measurement of top and back weld bead heights
- Radiography
- Metallographic examination of representative weld cross-sections
- Bend face and bend tests
- Transverse (to the welds) mechanical tests (i.e. UTS, YS and % Elongation).

Refer to Appendix 12 for test results.

5.9 Assessment of feasibility of HDGMA welding in Horizontal Out-of-Position

The feasibility of welding in the Horizontal position with the HDGMAW technique has been successfully demonstrated, with both 3/32" (2.38mm) and 1/16" (1.59mm) diameter welding filler wires. The main thrust of this evaluation revolved around the joint design and welding parameters with each of these two welding filler wires. Starting with the welding parameters developed for welding in the flat down hand position (Table 5) and progressing to trying different welding parameters/joint design combinations, the most promising joint design turned out to be a half bevel, with the bevel machined onto the weld edge of the lower plate. This joint preparation is presented in Appendices 15-2 and 15-3. The primary challenge with welding in the Horizontal position was to achieve the delicate balance between the surface tension of the

molten pool and the constant gravitational pull on it from the instance of its deposition followed by its solidification. When these two variables are not balanced, the Horizontal welds tend to develop a pronounced undercut at the upper (i.e. away from the ground) toe (or edge) of the outer (versus top in the flat down hand welding position) and larger weld bead. As a result, the efforts to weld in this position concentrated on simultaneously maintaining a stable arc and controllable flow & solidification of the molten pool, while trying to consistently achieve the weld attributes (i.e. geometry and sound weld quality) that meet the specified requirements in Appendix 2. Appendix 15-1 shows the weld fixture set-up used for Horizontal Out of Position (OOP) welding and a representative cross-section. Appendix 15-2 and Appendix 15-3 present the conditions that yielded the "most promising" results with the with the 3/32" (2.38mm) diameter welding filler wire and the 1/16" (1.59mm) diameter welding filler wire, respectively.

Representative welds produced in the Horizontal position with both diameter welding wires, were tested with non-destructive and destructive tests. However, some of the tests were not completed prior to the termination of the program. The tests showed that:

1. The welds, whose representative cross-sections were checked by metallographic examination, contained a moderate amount of porosity at its upper portion (Appendix 15-1). To better quantify the level of weld porosity in this weld and check whether it meets its allowed level (Appendix 2), will require its radiographic inspection. The planned radiography was not carried out, due to the termination of the program.
2. The height of the top weld reinforcement was typically between 0.090" (2.29mm) and 0.105" (2.67mm), which is similar to the results obtained with HDGMA welds produced in the Flat Down Hand position.
3. Dye Penetrant tests on the representative weld had no indication of surface breaking discontinuities (e.g. cracks, pores, etc.).
4. Face and Root Bend tests passed without cracking in the weld and/or the parent metals. The bend tests were of the Wrap-Around type using a 6.66T anvil diameter, where T is the thickness of the parent metal.

Preliminary evaluations of the HDGMAW technique's tolerance to concurrent variations in joint gap and vertical mismatch between the parts, while welding in the Horizontal position, show that the technique can tolerate a maximum 0.060" (1.5mm) joint gap & 0.040" (1.0mm) vertical mismatch between the parts being welded. This is comparable to the tolerance to parts fit up achieved when welding in the Flat Down Position (Appendix 11 – Figure A11-11).

The remaining Destructive Tests were discontinued when the program was terminated.

5.10 Testing of HDGMAW for Acceptance as a New Weld Process

Because the HDGMAW technique is considered as a new process by some members of the NAVSEA team, they requested additional tests of weldments produced with this method, as part of its qualification. Appendix 4 presents NAVSEA's e mail of July, 2, 2012 in which they specify the type of additional tests. Of the specified tests in this email, Porosity, Corrosion and Weld Distortion evaluations were completed prior to the-termination of the program.
To carry out the additional tests requested by NAVSEA, the member shipyards were provided with six 5083-H116 plates each being 2' (610mm) long x 1' (305mm) wide and 5/16" (8mm)

thick. These plates were to be welded by the member shipyards with the Gas Metal Arc Welding (GMAW) process, using their welders and qualified procedures. Two of these plates were used for weld procedure verification and the remaining four plates were welded into two separate test weldments, to be used as the baseline against which to compare the two HDGMA test weldments produced at the Alcoa Technical Center. The Baseline and HDGMAW weldments were tested in the exact same manner. The tests and comparisons of results between the Baseline GMA and HDGMA weldments, are presented below:

5.10.1 Porosity

Porosity was assessed by metallographic examination of representative cross-sections and radiography of the welds. The radiography of the welds was done both in the as welded condition, where the top and back (root-side) weld beads were left intact and post-machined condition where both of these beads were removed flush with the top and back side surfaces of the weldments. Both the single pass HDGMA and multi-pass Baseline GMA welds contained acceptable levels of porosity. The single pass HDGMA Welds had 90% less porosity than the multi-pass Baseline GMA welds. Representative cross-sections of HDGMA and Baseline GMA welds are shown in Appendix 16-1.

5.10.2 Corrosion

Corrosion Comparison on HDGMAW to Baseline GMAW was done using the XM-308 24hr ASSET (ASTM G66) test. The tests were performed on the top and root sides of the weld in the as welded condition and following a seven day exposure to 100^0 C. The corrosion resistance of the Baseline GMA and HDGMA welds were comparable. There was no evidence of Exfoliation Type Corrosion in any of the weldments produced with either of the processes. Some pitting corrosion was seen, which is expected with this type of test. All specimens produced with the two welding techniques in the as welded condition passed with a rating of PA. All specimens produced with both processes passed with a PB rating following a seven day exposure at 100^0C. There was no evidence of preferential corrosion in the HAZ. There was some enhanced pitting corrosion in Baseline GMAW in the Parent Material. At this point, neither the significance of this enhanced pitting in the Baseline GMA weldments nor its cause, are known. Detailed ratings and pictures of the test specimens are shown in Appendix 16-2.

5.10.3 Weld Induced Distortion

The plates were measured with a Coordinate Measurement Machine (CMM) prior to welding. The plates were marked so that measurement reference points were re-used for the post weld measurement, thus implementing a coordinated measurement. This enabled the post weld CMM measurements for out of plane distortion and lateral shrinkage to be made at the same locations as the pre-weld measurements. Also, this allowed any deviation in the component parts to be subtracted from post weld measurements so that the distortion calculation did not include any contribution from the component part tolerances.

The plates used for the GMAW to HDGMAW comparison test weldments had very low levels of deviation from flat. Also, the width of plates [1’ (305mm) dimension] was closely controlled because the edges of the plate were machined. This provided for a very good gap and vertical mismatch at fit-up and it minimized any impact of the components on the weld distortion measurement.

The weld distortion measurements for the HDGMAW and the Baseline GMAW processes are shown in Appendix 16-3. The plots are a top view of the weldment with the weld face labeled. The location of the Z (up/down) reference points are shown. The datums for the Y direction were on the bottom edge, so, lateral shrinkage across the weld will be evident on the edge measurements shown at the top of the page. Each measurement point is shown with a deviation box. The sign convention is such that measurements with a positive deviation are proud of the pre-weld measurement and those with a negative deviation are shy or the pre-weld measurement. The deviation boxes are also color coded. Positive deviations have warm colors (yellow, orange, red) and negative have cool colors (green, cyan, blue). Any deviations outside ±0.080” (±2mm) are red (positive) or blue (negative). The Baseline GMAW had higher out of plane distortion than HDGMAW by a factor of 4.5X. Also, the Baseline GMAW has higher lateral shrinkage by a factor of 2.4X. These are significantly higher levels of distortion and shrinkage. This significant improvement with the HDGMAW technique stems from the combination of lower total welding heat input per linear length, achieved with deposition of a single weld pass, and the complete penetrating of the weld through the joint, resulting in a more balanced weld induced distortion about the joint’s neutral axis.

5.11 Cost Modeling of the HDGMAW and Manual GMAW Processes

A detailed cost model was completed as part of Phase I. This is based on the material thicknesses, weld lengths in the design and the weld positions in the assembly sequence. The complete report for this cost model is presented in Appendix 17.

The cost model was created using the SEER-MFG commercial cost estimation software system. This system is employed by several major Defense Original Equipment Manufacturers. Labor, material, and tooling estimates for major steps are developed based upon industry standards. These include plasma cutting, routing, material transfer, part fit-up, multi-pass GMAW welding, inspection and rework operations. Labor costs are based upon time standards (calculated by SEER-MFG) and labor rates that are assigned by user. The user has the ability to add multiplication factors to adjust the standard rates form the SEER-MFG database.

The cost assumptions including labor rates and consumable costs are given in Appendix 17 Figure A17-2. Non-recurring costs are not included in the cost model. Non-recurring costs were considered by the limits on the cost of the HDGMAW systems for Flat Down Hand and Out of Position welding that were part of the Go-No Go Criteria for the project.

The primary inputs to the cost model were the flow paths for the Baseline GMAW and HDGAMW processes. Flow paths were developed for two cases for each process: Panel Line welding of panels or plates in the Flat Down Hand Position and welding in Module Erection or Final Erection in either the Flat Down Hand, Horizontal or Vertical Positions. The flow paths are presented in the following figures.

- Appendix 17, Figure A17-3 – Panel in Module Build – Baseline GMAW – FDH Position
- Appendix 17, Figure A17-4 – Panel in Module Build – HDGMAW – FDH Position
- Appendix 17, Figure A17-6 – Module to Module Erection – Baseline GMAW
- Appendix 17, Figure A17-7 – Module to Module Erection – HDGMAW

The detailed breakdown of the cost comparison for a Panel Line Flat Down Hand Position weld with both process is presented in Appendix 17, Figure A17-5. This figure presents the cost of each flow path step for both processes including the labor hours per unit and the labor cost per unit. For the HDGMAW process, there is an additional comment on the relative cost of each flow path step relative to Baseline GMAW. There are some steps that the cost is estimated to be exactly the same for both processes. Others are a similar step, but, are estimated to involve more labor for HDGMAW than what is required for the Baseline GMAW. This is noted with the assumed labor multiplier. The cost of the actual welding with HDGMAW is based on the welding speed demonstrated during Phase I welding. Finally, the total estimated cost savings for this particular weld joint is summarized. Appendix 17, Figure A17-8 presents a similar comparison for a module to module weld.

Appendix 17, Figure A17-9 shows the cost comparison for all applicable welds in the complete structure. This includes both panel to panel and module to module welds. These welds are in multiple positions: Flat Down Hand, Horizontal Out of Position and Vertical Out of Position. The average estimated cost savings of all these welds was 22%. Appendix 17, Figure A17-10 shows only welds in the Flat Down Position. The average estimated cost savings of all these welds was 21%.

One element of the flow path that is difficult to estimate in a cost analysis is the labor time for part fit-up. This is highly dependent upon the geometry of the parts, the assembly sequence and the effect of component tolerances and weld distortion from previous welds. The HDGMAW process will require tighter control of joint gap and vertical mismatch to achieve consistent weld quality. So, there will be higher labor cost to achieve the required joint gap and vertical mismatch. It was estimated that this would be 1.5X the labor of the Baseline HDGMAW. Feedback from the shipyards is that this factor should be higher and, in fact, it may not be feasible at all to meet these limits in some conditions. So, a sensitivity analysis was done to find the breakeven point for the HDGMAW process as a function of the multiplier used for the fit-up cost component. Appendix 17 Figure A17-11 presents the cost savings as a function of this multiplier. The savings for the HDGMAW process is reduced to zero if the labor required for fit-up for the HDGMAW process is ~2.6X of the Baseline GMAW process fit-up labor component. Note that all welds in the cost model are for 5/32” (4mm) thick material. There would further savings available for thicker materials which would require additional weld passes with the Baseline GMAW process. This would increase the factor for the breakeven point.

5.11.1 System Integrator Survey

This survey was not completed prior to the termination of the program. However, discussions were held with six system integrators during Phase 1 activities. At the beginning of Phase 1, five of the system integrators were invited to give presentations on their capabilities. The general requirements of the planned system were reviewed with the system integrators during these meetings. A detailed system specification was not given, however. The system integrators were asked for a rough order of magnitude (ROM) quote for a system to be used in Phase 2 using their best judgment of meeting requirements that were reviewed during their visits. They were also asked to express any concerns they had with the technology or the project. The sixth system integrator provided a preliminary quote for the project proposal. All six system integrators were

technically capable of providing the system for Phase 2 of the project. Two of the six system integrators declined to provide a quote and were omitted from further consideration. The quotes and interactions with the System Integrators indicated to the Alcoa team that there were viable candidates for Phase 2. The final down selection was not completed and the request for quote for the Phase 2 System was not pursued because of the decision to terminate the project.

5.11.2 Specification for Phase 2 HDGMAW System

The specification for the Phase 2 HDGMAW System was not initiated prior to termination of the program. It will not be included in this report.

6.0 Welding Performance Versus Targets Checklist

Acceptance criteria for high deposition GMA welds were developed to guide a recommendation concerning the continuation of this program into Phase 2. These criteria are listed in the “Go / No Go” checklist in Appendix 18. This checklist consists of a listing of a Parameter or Performance Requirement, Target Metric, the Demonstrated Performance, Pass/Fail Indicator and a field for Comments.

Physical properties measured were from welded plates produced on the prototype High Deposition Gas Metal Arc Welding (HDGMAW) system configured at the Alcoa Technical Center. Welds up to 5’ (1524mm) long were produced on this equipment from 5083-H116 plate using 5183 filler wire.

Where ever possible, the metrics were determined from the Targeted Weld Attributes (Appendix 4) and applicable Military & NAVSEA standards. Some criteria on the “Go / No Go” checklist use a comparison with standard GMA welded plate to provide directional information for the Phase 2 recommendation because standards do not include criteria for these parameters. The standard GMA data were obtained from welds produced on the same lot of 5/16” (8mm) thick 5083-H116 plate welded at a shipyard.

There are forty Parameter or Performance Requirements in the Go/No Go Checklist. Five of these failed to meet the Target Metric. Evaluations for seven were not completed prior to the termination of the program.

7.0 Project Risk Assessment

The Office of Naval Research maintains a continuous understanding of a program’s ability to be implemented through a periodic Project Risk Assessment (PRA). This standard document is completed for all ManTech Programs. The HPAM program’s PRA as reported at the LCS IPT April 25, 2013, meeting is contained in Appendix 19.

8.0 Phase 1 Conclusion

Technical characteristics of the HDGMAW technique were reviewed by CNST and the shipyards toward the end of Phase 1, to determine the likelihood that this welding technique will be adopted and implemented by the shipyards at the conclusion Phase 2 of this program. They have concluded to terminate the program, because they rendered this technique unlikely to be used in current production at the Austal and Marinette shipyards. The three main factors that led to this decision were:

1. The capability of the HDGMAW technique to weld joint gaps and part vertical mismatches only up to a maximum of 0.080" (2mm).
2. The need to use temporary backing bars as this is an additional step in joint fit-up.
3. The need to grind-blend the toes (or edges) of the back side (or root) of the welds produced with this welding technique, in order to guarantee the required >90° reentry angle as specified in Appendix 4.

It was felt these factors would reduce the economical benefit of HDGMAW sufficiently to preclude its use. CNST recommended, and ONR agreed, that the HPAM program would end after the Phase 1 cost modeling and summary reporting tasks were completed.

Also, there were two elements of the Weld Procedure Qualification that were not met. The Ultimate Tensile Stress requirement was not met and the Top (Face) Weld Reinforcement Height was on the borderline of its requirement. These requirements would require further development to resolve if they could not be accepted as exceptions to the applicable NAVSEA standards.

Given all results from Phase I and the recognized need for further development to meet all Go/No Go criteria, the most likely future application of the HDGMAW in the shipyard industry would be a traditional panel line with thicknesses at the upper end of the 5/32"-5/16" (4mm-8mm) thickness range. This type of application would reduce the cost impact of placing the temporary backing bar and would increase the benefit from the reduced number of welding passes.

9.0 Acronyms

ATC – Alcoa Technical Center, located 20 miles east of Pittsburgh, PA

CMM – Coordinate Measurement Machine

CNST – Center for Naval Shipbuilding Technology

FDH – Flat Down-Hand

GMAW – Gas Metal Arc Welding

HAZ – Heat Affected Zone

HPAM – High Productivity Aluminum Manufacturing

HDGMAW – High Deposition Gas Metal Arc Welding

IPM – Inches per minute

LoF – Lack of Fusion

ONR – Office of Naval Research

OOP – Out of Position

PRA – Project Risk Assessment

SSSP – Single Side, Single Pass

TBB – Temporary Backing Bar

TYE – Material mechanical properties: Tensile Stress, Yield (Ultimate) Stress, Elongation

WPQR – Weld Procedure Qualification Record

WPS – Weld Procedure Specification

HIGH PRODUCTIVITY ALUMINUM MANUFACTURING

Appendices 1 through 19 of Final Phase 1 Report for Period March 2012 – July 2013

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July 2013

CNST Base Task Order Agreement Number 2012-440

PREPARED FOR:
CNST
5300 International Boulevard
Charleston, SC 29418

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)* 31-07-2013	**2. REPORT TYPE** Phase 1 Summary	**3. DATES COVERED** *(From - To)* March 2012 to July 2013

4. TITLE AND SUBTITLE CNST – High Productivity Aluminum Manufacturing Appendices 1-19 of Final Phase 1 Report	**5a. CONTRACT NUMBER** 2012-440 **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHOR(S) Philip Gacka, William H. Grassel, Israel Stol, Kyle L. Williams, Daniel M. Myers, Kirit Shah, D. J. Spinella	**5d. PROJECT NUMBER** **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Alcoa, Inc. 100 Technical Drive Alcoa Center, PA 15069	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) SCRA Applied R&D 5300 International Boulevard Charleston, SC 29418	**10. SPONSOR/MONITOR'S ACRONYM(S)** **11. SPONSOR/MONITOR'S REPORT NO's.**

12. DISTRIBUTION / AVAILABILITY STATEMENT
DISTRIBUTION STATEMENT C. Distribution authorized to U.S. Government agencies and their contractors for critical technology reasons, April 2013. Other requests for this document shall be referred to CNST, 5300 International Boulevard, Charleston, SC 29418, 843-760-3200.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This report documents the first year of a two year program to develop single side, single pass butt welding capability of aluminum 5083 marine plate used for LCS construction. Welding process parameters and equipment techniques were developed to successfully weld 5/16" (8mm) thick plate. Technical limitations of this process made it unlikely it would be implemented in LCS shipyards. It was recommended not to continue this program to the planned second year, Phase 2 tasks.

15. SUBJECT TERMS
butt welding, LCS, high deposition, GMAW, HDGMAW, aluminum 5083

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**	UU		W. Southerland
Unclassified	Unclassified	Unclassified			**19b. TELEPHONE No.** 843-760-3482

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

Appendix 1 – Detailed Listing of Phase 1 Personnel

Program Sponsors & End Customers

- Neil Graf – ONR Program Office, Code 03TMT
- Kevin Carpentier – CNST Director
- Dale Orren, CNST Deputy Director
- Bob Schaffran – CNST Technical Director
- Warren Southerland – CNST Project Manager
- Carl Roxbrough – CNST Contract Representative
- Tony Smith – Program Office, PMS 501
- Cathy Wong – Tech Warrant Holder, NAVSEA (05 P2)
- Kim Tran – Materials Engineer NSWCCD, Code 611

Alcoa Team

- Bill Grassel – Program Manager
- Phil Gacka, Israel Stol, Kyle Williams, Daniel Myers, Rick Dulski – Technical Team
- D. J. Spinella, Rao Vemuri – Cost Projections
- Sara Yount – Business Point of Contact
- Lambra Nemeth – Government Property
- Karen Williams – Procurements
- Sally Veyo – Accounting
- Samantha Stephens – Trade Compliance
- Sherri McCleary – Management
- David Williams – Marketing

American Bureau of Shipping (ABS)

- Jon Fallick – Weld Quality Assessment and Validation

Austal USA

- Mike Webster – Technical and Business Development Manager
- Amy Dewise – Manufacturing Engineer
- Shawn Wilber – Naval Architect
- Paul Mattison – Quality Foreman
- Scott Yeager – Contracts Administrator

Marinette Marine Corporation

- Robert Watkins – Director of Engineering
- Scott Wellens – Director of Facilities Improvements and Quality Assurance
- Charlie Jackson – Senior R&D Engineer
- Tracy Coveyou – Assistant Director of Manufacturing
- Bruce Williams – Superstructure Manufacturing Supervisor
- Dan Roland – Quality Technical Coordinator
- Todd Christian – Industrial Engineer
- David Redburn – Contracts Manager

Appendix 2 – Welding Parameters for High Productivity Aluminum Welding Program

Alcoa	Austal 2012-04-12	Marinette Marine 2012-04-23
Bill Grassel	Wayne Stoner	Tracy Coveyou
Phil Gacka		Charlie Jackson
Israel Stol		
Kyle Williams		

Weld and material characteristics selected for use in developing the single side, single pass welding process follows.

1. Square butt joints will be the joint geometry used. The preference is to not need to bevel plate edges for welding, but edge geometry may be required to permit seam tracking and/or obtain the required weld bead geometry.

2. 5083-H116 plate will be the base material welded in this program. Welding of 5083-H111 extrusions has not been selected as a targeted application.

3. Plate thickness will be 8 mm ±1 mm. There is little interest in using this technology for plate less than 4 mm.

4. Filler alloy will be 5183. Filler wire alloy 5356 is typically what is used at Marinette. This is the same S number as 5183; Marinette agreed to 5183 being used to develop this welding process.

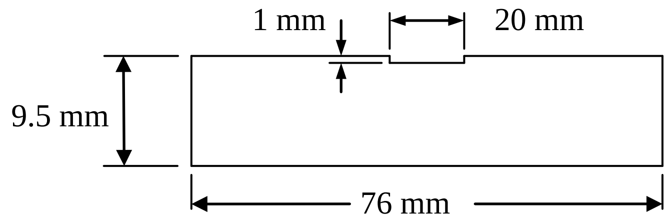
5. Welding process development will first be done for flat down hand welding as outlined in the Phase I program plan. After this is successful, the feasibility of horizontal out of position welding will be assessed. Regarding out of position welding at Marinette, roughly 30% is horizontal and 70% vertical. Because the highest probability of success with out of position welding will in the horizontal direction, Marinette supports pursing horizontal out of position welding as part of this program.

6. The dimensions of the weld assembly mockups to be used to develop and demonstrate the process at different stages of the program will be as follows:
   - At the beginning of this program, Alcoa will work with joint mockups whose dimensions (i.e. length & width) will be of its choosing.
   - At the end of Phase I of the program, Alcoa will demonstrate welding with the process at the Alcoa Technical Center (ATC) on joint mockups that are 5ft long.
   - The mechanized system to be developed and demonstrated in a shipyard at the conclusion of Phase II will be carried out with a 10 to 12ft long assembly mockup. The production system developed after this program is concluded will have a target to produce welds at least 40 feet long.

7. Nominal plate fit-up ranges in production the mechanized system needs to accommodate are:
   a. Joint gap: 1.5 mm
   b. Offset: 1.5 mm

The maximum root opening was stated as being 4.75 mm. If the demonstrated maximum joint-gap and plate-offset that can be tolerated by the High Deposition Buried GMA process with the specified program parameters are less than the targets in 7a and 7b, the shipyards and Alcoa will determine actions needed to make this a production process.

8. Anodized aluminum recessed back-up bars typically used by Alcoa in development activities will be used in the SSSP program. Typical back-up geometry is shown in the figure. The 1mm recess may be rounded at its bottom rather than "squared" as shown.



Back-ups used in shipyards may be made of other materials and configurations, such as segmented ceramics, in order to obtain features needed for specific welding applications.

Whatever back-ups are used in shipyards, they must be removable after welds are made.

It was agreed that breaks in horizontal out of position welds would be reviewed on a case-by-case by the shipyards for each production weld. It was also agreed that all the development work with this welding process will be carried out by Alcoa with the same type of recessed back-up.

9. The surface preparation technique that will be used prior to welding will be: solvent cleaning and drying the part edges to be welded followed by brushing with a stainless steel brush.

10. The quality target included in this program's original proposal is:

"The targeted quality of the welds will be based on the Structural Welding Code, AWS D1.2/D1.2M:2008 or welds with: no internal or external cracks, consistent weld geometry, <10% internal weld porosity and amount of open weld porosity reduced by 30% compared to the open weld porosity obtained at the present time on the joint to be selected for welding in the flat down-hand with the HDGMA welding process."

During our April 12 meeting, we discussed specifying the weld quality to be at least to 2035 Class 1. Israel Stol will contact Jon Fallick to obtain the Naval Vessel Rules regarding weld quality, which will provide the target metric for this program.

11. An additional aspect of the SSSP welding system to monitor is the amount of space required in the vicinity of the weld. As SSSP welding equipment is specified and configured, shipyard team members should identify specific welds it would be used for and work with Alcoa to determine if the system being developed would function properly in production. This includes having sufficient room for the welding equipment, mechanized track system, and insertion/removal of the backing bars.

Appendix 3 – High Productivity Aluminum Manufacturing Gap Analysis

#	System Element	Classification	Description	Gaps, Considerations & Concerns	Exists at ATC for Process Development
1	Filler Wire	Consumable	Plan is to use 5183 alloy filler wire.	The shipyards do not use the same filler wire alloy, but have agreed to 5183 for this program. As long as filler wire alloy is within same group same functionality is expected. Change of filler wire alloy may require requalification.	Yes
2	Inert Gas	Consumable	Shielding gas for the arc.	Gas composition needs to be determined. Current plan is helium argon. May be different from current gas used in shipyards. Gas composition may be different for Flat Down Hand (FDH) vs. Out of Position (OOP).	Yes - we have all planned options available
3	Back-up Bar - Temporary	Equipment	Contain root side melt through and result in required root side geometry; must be easily removed after welding. Must be easily located relative to joint centerline.	Groove geometry not finalized for either FDH or OOP welding. Material needs to be specified. Ceramic may not be as effective in controlling root side reentrant angle. Metallic backup may get fused if gaps are large. Method for root side access when weld is perpendicular to ribs is yet to be developed. Method for securing is yet to be developed. Both are application specific & to be developed with the shipyards.	Yes - Anodized Al for FDH - 3 depths for evaluation. Nothing on hand for Ceramic or OOP welding.
4	Cable Track	Equipment	Method to supply required cables to all equipment that is moving along with track.	Use commercially available solutions to provide this capability.	Yes
5	Clamping Traversing System to Work	Equipment	Means to hold Traversing System relative to work piece in the field & resist movement during operation. Needs to accommodate out of position welding. Needs method to roughly align track to joint. Needs to fit within limits of the vessel structure, fixture elements, and geometric features of the parts being welded.	Need to evaluate if clamping is required for FDH. Assume no access to steel structure for magnetic clamping. Use suction, weld on tabs or other mechanical clamping to part edges. Specific design will be required.	Yes. Development will proceed with clamping system to an Acorn table since development will be done on small scale parts.
6	Inert Gas Method of Supply	Equipment	Supply shielding gas for the arc. Plan for a fixed inlet coupling on the system from the supply tanks. System will include flexible tubing to supply gas to the torch as it traverses. Shipyards must get inert gas to inlet.	Type of inert gas transmission line needs to be selected for transmission over long distances (e.g. 20 to 40'). Expect this to be commercially available technology.	Yes
7	Operator Pendant	Equipment	Provide one point of input for operator to the system (power supply, wire feed, positioner)	To be provided by System Integrator. Expect this to be commercially available technology.	No. Development can proceed with current interface, however.
8	Seam Finder	Equipment	Method to measure the lateral position of the joint centerline and distance normal to the surface. Tactile and laser are the methods being considered.	Plan is to use commercially available seam finder. Reliability & robustness of current technology is not known to Alcoa. Detailed functional requirements are not yet known relative to welding with the HDGMAW process. Down selection of seam finder will be a factor in determining whether the shallow groove on the top of the joints is required or not.	No
9	Torch	Equipment	Means to apply wire & inert gas to the joint.	Torch similar to existing torch. Expect to use commercially available torch. Torch will not be new technology & there are no associated gaps.	Yes
10	Traversing System (Track & Carriage)	Equipment	Provides YZ Position of torch relative to joint, X translation for welding. Provides attachment points for all equipment that traverses during welding.	Expect to choose commercially available equipment for this function.	No. Current track only provides traversing function. Welding development can begin with this system.

<u>**Appendix 3 (cont'd)**</u>

#	System Element	Classification	Description	Gaps, Considerations & Concerns	Exists at ATC for Process Development
11	Weld Wire - Feed Mechanism	Equipment	Means to feed the weld wire from the spool to the torch.	Type & make to be decided with the chosen system integrator. Impacted by decision of where supply spool is located. Expect fewer problems because of selected weld wire alloy & thickness. Specific development and proof of concept relative to the HDGMAW required.	Yes
12	Weld Wire - Feed Spool	Equipment	Unwind for weld wire.	Target 16-30 lb. spool, but consider also drum enclosed welding wire. Economics of spool changes and determining if spool moves with torch will affect the design.	Yes
13	Welding Power Supply	Equipment	Provide & control electrical current to the weld joint.	Welding mode is not defined at this time. Will evaluate CV, CC and various types of welding current modulations (i.e. pulsing). Possible software/program specific to HDGMAW to be developed.	Yes, currently using Lincoln Powerwave 455 for development
14	Fixturing Method	Fixture	Provides a means to bring weld joints into contact & position surfaces to minimize mismatch.	Method is application specific. Development to be led by shipyards. Expect to use current method & refine as needed to meet the joint gap & mismatch requirements of HDGMAW after they are established.	No. However, not required for development since small scale parts are being used.
15	Travel Speed	Limit	Linear travel speed of torch at steady state.	Actual speed may be a function of plate thickness and orientation (i.e. welding position). The actual min, max, and nominal speeds need to be determined by development program.	NA
16	Maximum Mismatch	Limit	Relative position of two parts normal to weld face.	Current nominal value is 1.5 mm. The maximum target will be 3 mm. Development program will establish limits for HDGMAW.	NA
17	Maximum Root Gap	Limit	Relative position of two parts normal to weld joint.	Nominal is 1.5 mm. Development program will establish limits for HDGMAW.	NA
18	Start/Stop Transition	Limit	Limit for HDGMAW weld line in the structure - Clearance distance required to a perpendicular encumbrance.	Ways to handle physical interference between seam tracker and structure at end of weld may need to be developed.	No. Not required for development.
19	Aluminum Extrusion	Material	Extruded panels are expected to react similarly to plate with this welding system. Thickness range is same as plate.	Within the targeted alloy family, transition to another alloy should be able to be developed. Would require additional development & requalification of welding procedures. Other alloy families would require full development.	No. All development planned on plate.
20	Aluminum Plate	Material	Target application for demonstration is 5083-H116, 7.9 to 8.1 mm thick. Nominal thickness range to be welded by this system is 4 to 8 mm.	Within the targeted alloy family, transition to another alloy should be able to be developed. Would require additional development & requalification. Other alloy families would require full development.	Yes
21	Weld Operator	Personnel	Welding system operator.	No gaps. Current operators will be able to use this system after equipment specific training.	Yes
22	Surface Cleaning Prior to Welding	Procedure	Remove surface hydrocarbons & oxide removal as necessary. For this process development program, surfaces to be welded will be solvent cleaned and dried, followed by brushing with a stainless steel brush prior to welding.	Required practice may be different than current operations in the shipyard.	Yes
23	Tack Welding	Procedure	Method to secure & restrain parts after fit-up & prior to welding. Manual process.	Tack welds may affect the HDGMAW process & seam finder.	Yes

Appendix 3 (cont’d)

#	System Element	Classification	Description	Gaps, Considerations & Concerns	Exists at ATC for Process Development
24	Weld Edge Preparation	Procedure	Cut parts to manage gap & create bevel if needed.	Edge preparation requirements impact on economics to be determined. Need to translate gap requirement to appropriate requirements on edge preparation. Lube require **Appendix 3 (cont’d)**ments for edge preparation may impact cleaning.	Yes. Development will start with machined edges. Planned production processes will be used as needed.
25	Weld Repair	Procedure	Procedure to repair weld flaws.	Expect to use current accepted practices	N/A
26	Weld Restart after abnormal/unexpected termination	Procedure	There will be a restart process required that is specific to HDGMAW. This is not included in the scope for this project.	Default procedure would be to restart downstream of the termination and then use normal repair procedure between the abnormal termination & the restart.	N/A
27	Calibration Routine - Robot & Seam Finder	Software	Method to guarantee registration between the YZ position of the torch with the seam tracking device.	Expect this function to be part of the commercially available control system with the weld track/positioner.	No. Not required until seam tracking demonstration.
28	Control - Lateral & Stand-off Distance	Software	Feedback control system to position the torch in the normal to weld face & laterally. Uses seam tracker as the feedback measurement.	Expect this function to be part of the commercially available control system with the weld track/positioner. Specific development for HDGMAW may be required.	No. Not required until seam tracking demonstration.
29	Control - Traversing System	Software	Controls traversing action of the Carriage.	Must have limits/stops near end of travel.	Yes
30	Diagnostic	Software	Method to interrogate the status/operation of any equipment/software unique to HDGMAW. Remote interrogation via the internet is required.	Expect limited functionality. Commercially available technology to be used in production by the shipyards.	No
31	Torch Oscillation	Software	Lateral movement of torch to accommodate joint gaps.	Will be considered but is not likely to be applicable with HDGMAW. It could result in excessive weld reinforcement & arc instability.	N/A
32	Weld Start, Weld Stop & Crater Fill Program	Software	Effective means to start/stop welding.	Run-in & run-off tabs will be used for development.	Yes - Run-in/run-off tabs only. The Run-in and Run-off tabs will also be used during the demonstration in the shipyards, at Phase II of this program.

Appendix 4

Targeted Weld Attributes to be Used for Welds Produced with the High Deposition Gas Metal Arc Welding (HDGMAW) Process Under the MANTECH Program

Israel Stol (Alcoa) / Jon Fallick (ABS)
2012 June 01

• Thickness of top Weld-Reinforcement Note: Once the actual welding trials commence, the achievable thickness of Weld-Reinforcement with the 0.3in (8mm) thick Square-Butt joint will be determined. If the listed requirement cannot be met, a Vee or half Vee top joint opening may be needed or this requirement may need to be relaxed.	– <0.09in. (2.29mm)
• Re-entrant angle between the base plates and the toes of the top Weld-Reinforcement	– >90°
• Root surface Concavity	– Not allowed
• Root surface Convexity	– 0.09in. (2.29mm) max.
• Re-entrant angle between the base plates and Convex Root Contour, in the as-welded (not ground or machined) condition.	– >90° Note: This re-entrant angle may be smaller than 90° with the High Deposition GMAW process. The welding trials will determine what it will be and adjustments for this requirement may have to be made.
• Thickness of the Face (top) and Root (backside) sides of the welds.	– Shall have enough thickness (i.e. height) to allow grinding of the toes of the welds smoothly into the base metals in order to ensure a minimum Re-Entry angle >115° for fatigue sensitive Class 1 welds.
• Undercut	– Max. 0.03in. (0.79mm) or 10% of the minimum thickness, whichever is less.
• Burn-through	– Not allowed
• Incomplete fusion	– Not allowed
• Heat checks (i.e. Fissures or tears in the weld Heat Affected Zone)	– Not allowed
• Incomplete Penetration	– Not allowed
• Cold shut	– Not allowed
• Internal weld Cracks	– Not allowed
• Surface-breaking Cracks, at the weld start and along the weld	– Not allowed
• Melt-through	– NA
• Weld termination	– Crack free with the Crater Pit above the top surface of the part or removed from the weld through the use of a run-off tab.
• Arc strikes on welds and adjacent parts Note: Where arc strikes are removed, the resulting cavities will not exceed 0.03in. in depth or 10% of the adjacent base metal thickness, whichever is less	– Not allowed

Appendix 4 (cont’d)

• Weld spatter	– <0.125in. (3.18mm) in diameter or length of tightly adhering spatter, except in areas to be inspected by UT, PT or RT.
• Weld porosity (Per Mil-STD-2035A of 15 May 1995, section 5.2.4.4, for RT inspection)	– **M**aximum total area of permitted in 1in. weld length =0.015xT inch x 1in., where T is the thickness of the parts being welded. – **R**andomly dispersed porosity shall not exceed the limits of Figure 9 from MIL-STD-2035A, attached below. – **C**lustered or concentrated porosity, when evaluated with other porosity indications, shall not to exceed the maximum number shown in Figure 9, in any 6 inches of weld.
• Maximum permissible offset between parts	– TBD experimentally in the program for the chosen joint thickness (e.g. 0.3in.)
• Maximum permissible joint gap between the parts	– TBD experimentally in the program.

MIL-STD-2035A

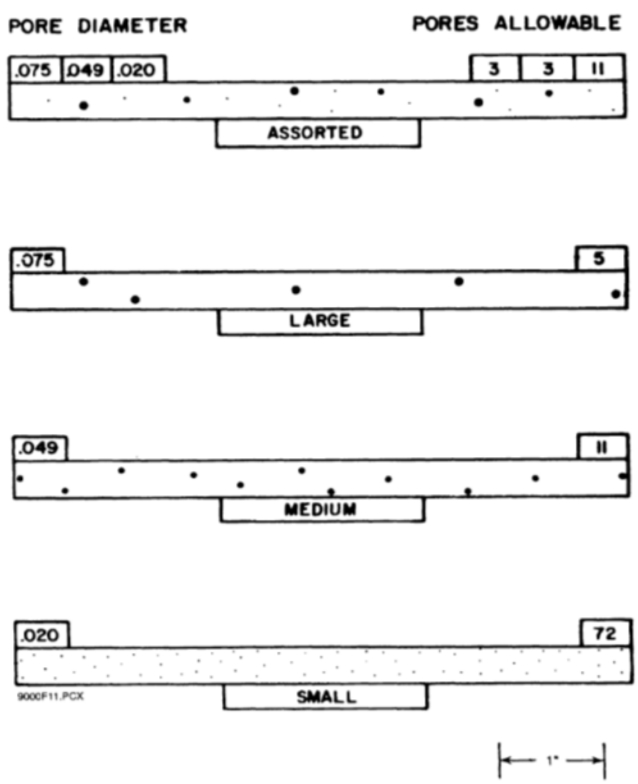


FIGURE 9. *Radiographic porosity Class 1 and Class 2 (1 percent T/inch per 6 inches), T equals 3/8 inch (0.0225 in^2 total porosity area).*

Figure A4-1 – Radiographic Porosity Class 1 and Class 2 - MIL-STD-2035A

Appendix 4 (cont'd)

-----Original Message-----
From: Tran, Kimngoc T CIV NSWCCD West Bethesda MD, 6110 [mailto:kimngoc.tran@navy.mil]
Sent: Monday, July 02, 2012 12:45 PM
To: Grassel, William H.
Cc: Wong, Catherine R CIV SEA 05, SEA 05P
Subject: RE: Technology Transition Plan

Bill,

I've discussed the transition plan with Cathy Wong. Since HDGMA is a new welding process, there will be additional tests that are required for Navy implementation approval. Besides the standard tensile and bend testing for weld qualification, we require the following:

1) Yield strength and elongation values for welds tested with and without the reinforcement
2) G66 and G67 testing
3) G66 and G67 testing after exposure to 100 deg C for 7 days
4) Metallography including etching of the HAZ for beta phase
5) Hardness traverses across the weld/HAZ/adjacent base metal
6) Fatigue testing if the process is intended to be used for any structural applications

Additionally, NDE needs to be defined. During weld procedure qualification, the welds will be required to pass RT inspection. However, how will production welds be inspected?

Have applications been identified? Will there be any changes to current joint designs?

Thanks,
Kim

Appendix 5

ManTech Shielding Gas Weld Trials

August 3, 2012

Objective: Evaluate the influence shielding gas has upon the High Deposition Gas Metal Arc Process (HDGMA)

Materials, Joint Configuration, and Inspection

Base Metal: 5083-H116, 0.313 inches thick

Joint Type: Square Butt with temporary backing, 0.0 inch root opening

Electrode / Filler: ER5183 0.063 inches diameter

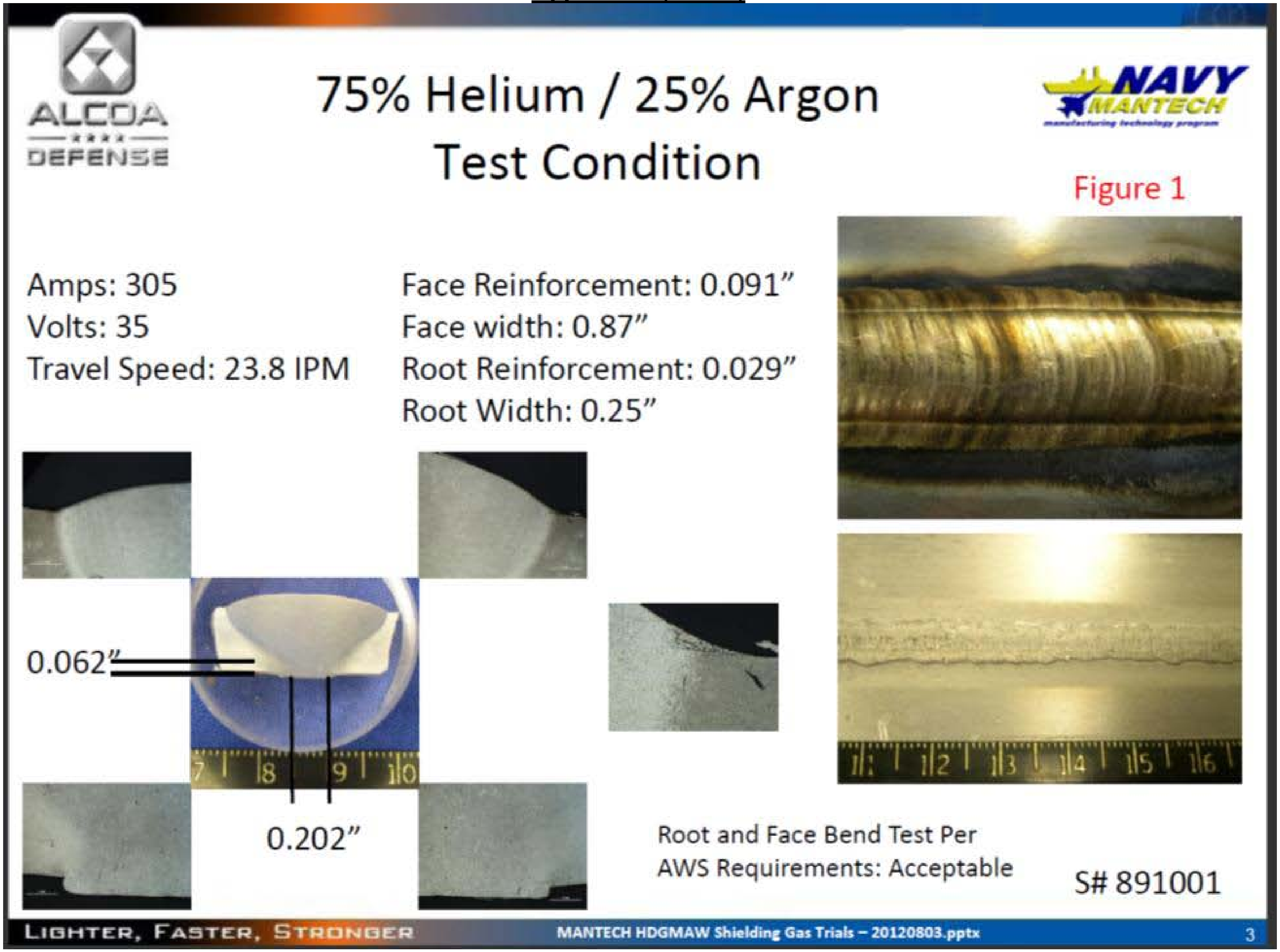


Figure A5-1 – 75% Helium/25% Argon Test Condition

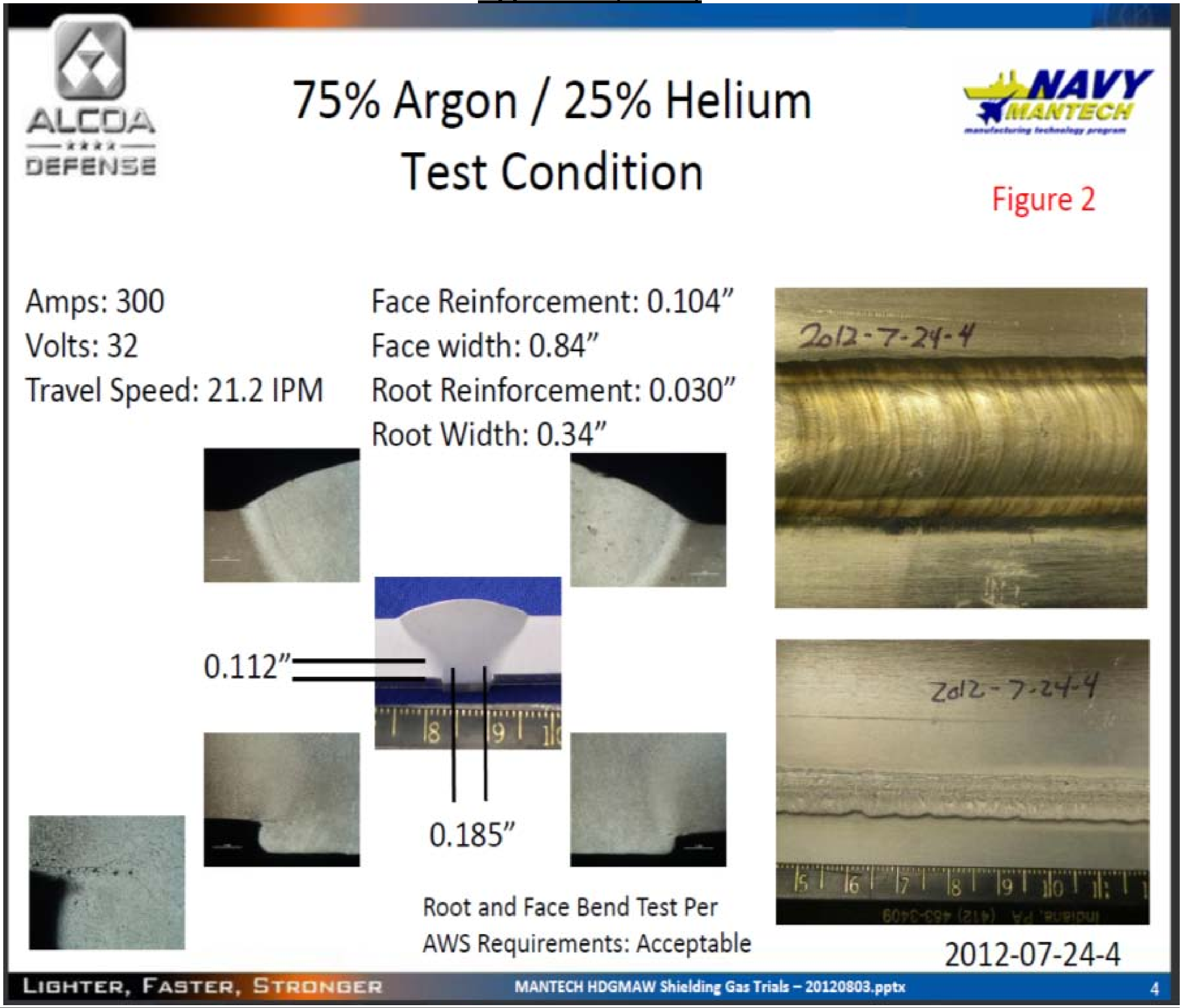


Figure A5-2 – 75% Helium/25% Argon Test Condition

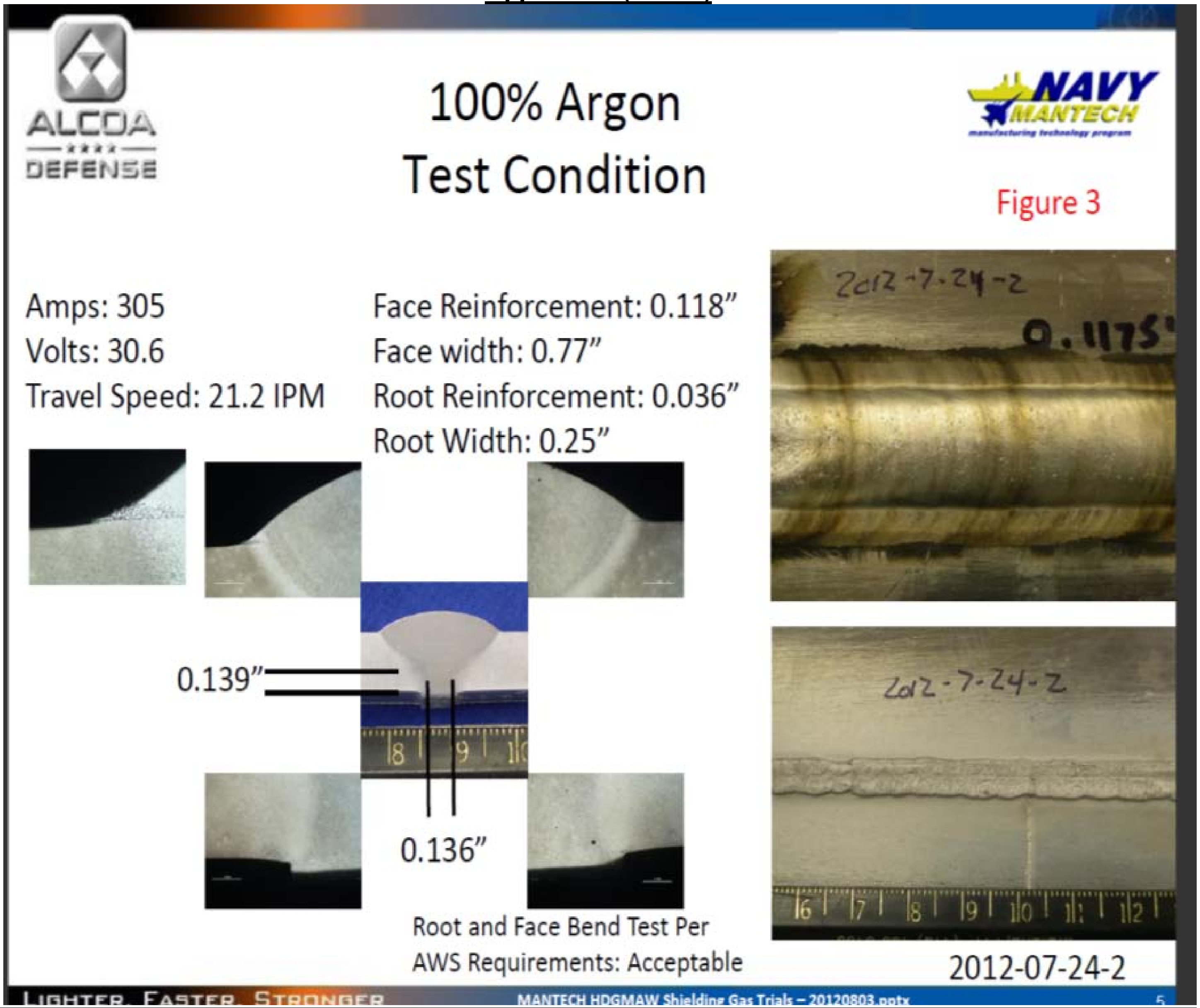


Figure A5-3 – 100% Argon Test Condition

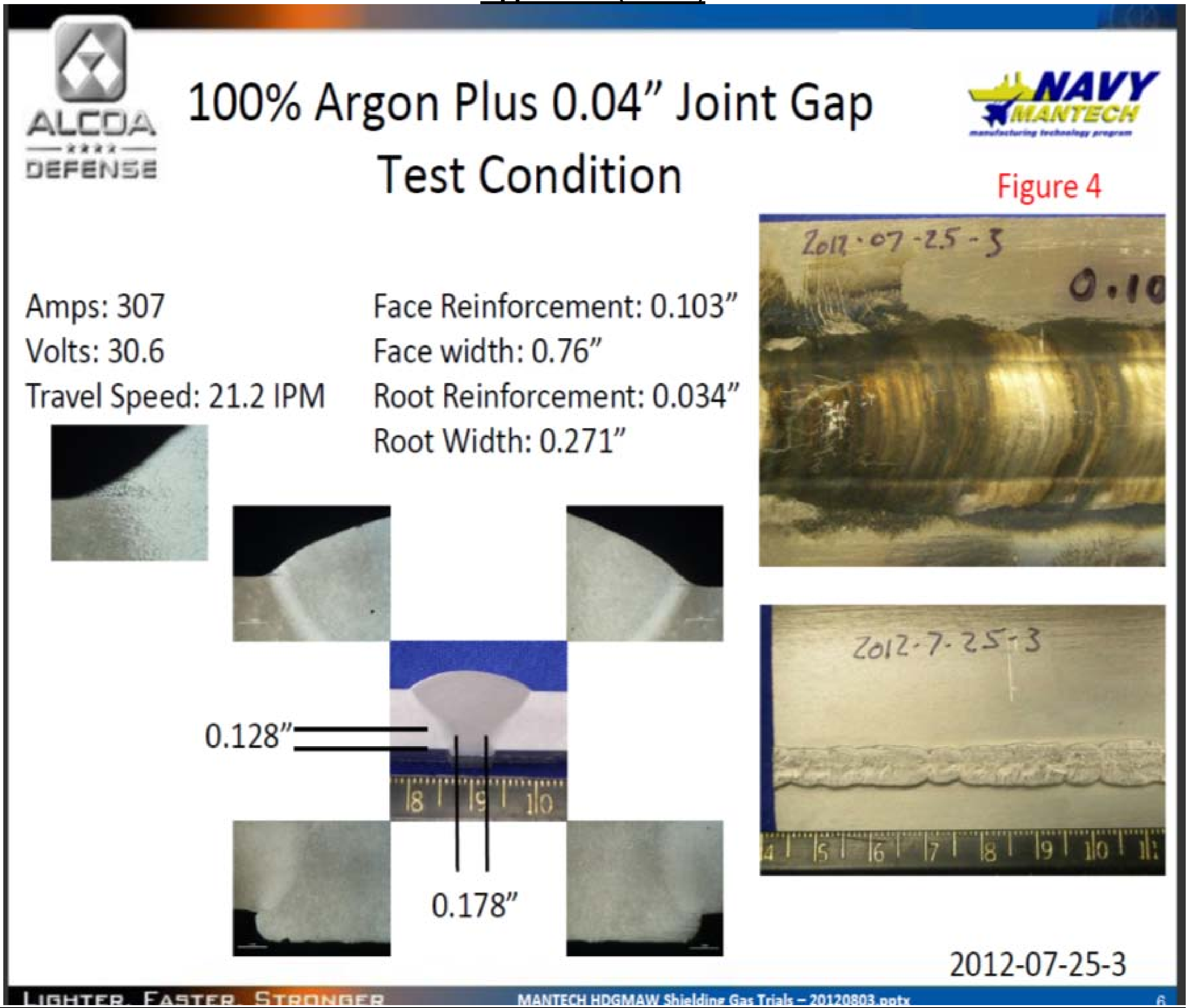


Figure A5-4 – 100% Argon Plus 0.04" Joint Gap Test Condition

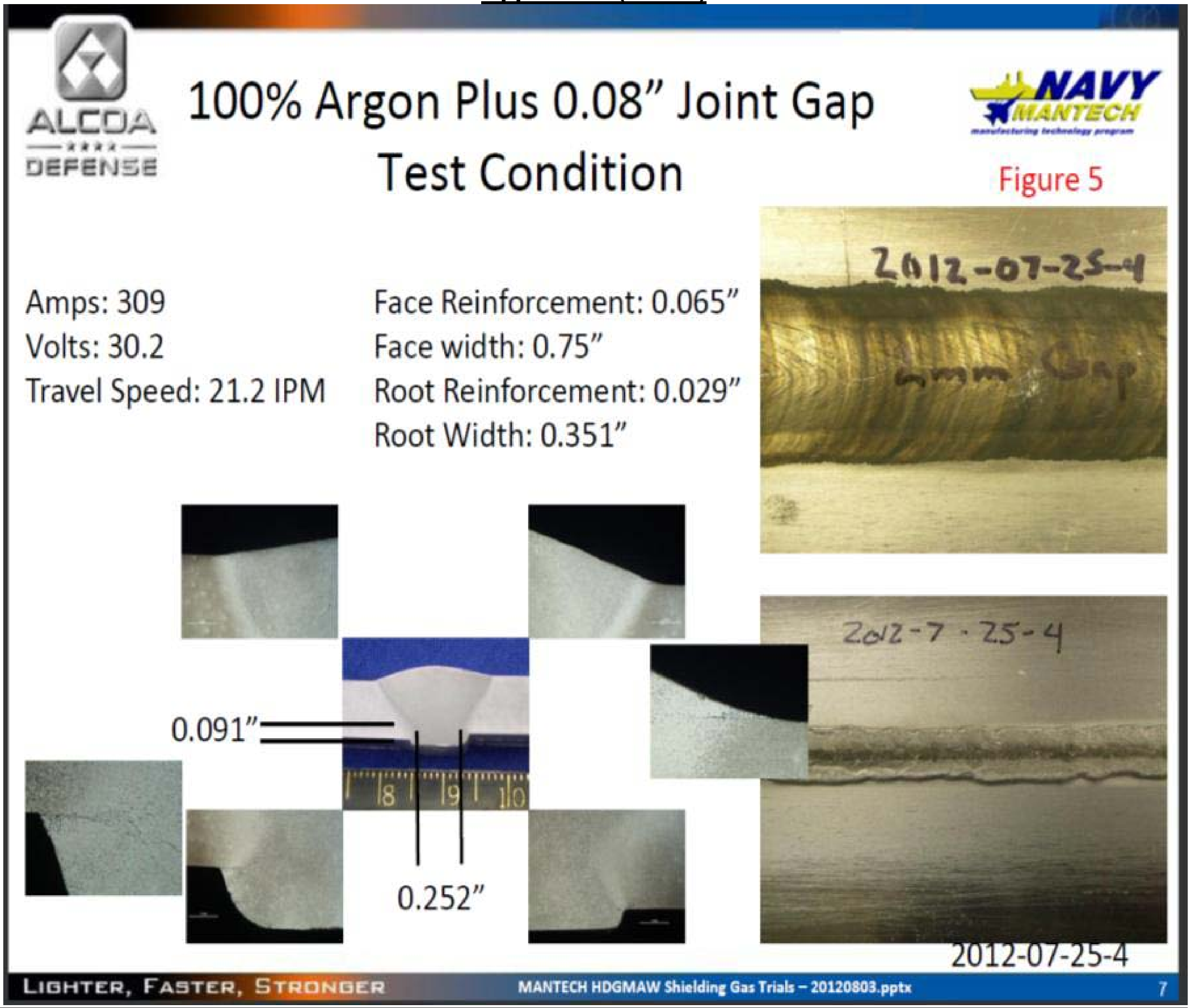


Figure A5-5 – 100% Argon Plus 0.08" Joint Gap Test Condition

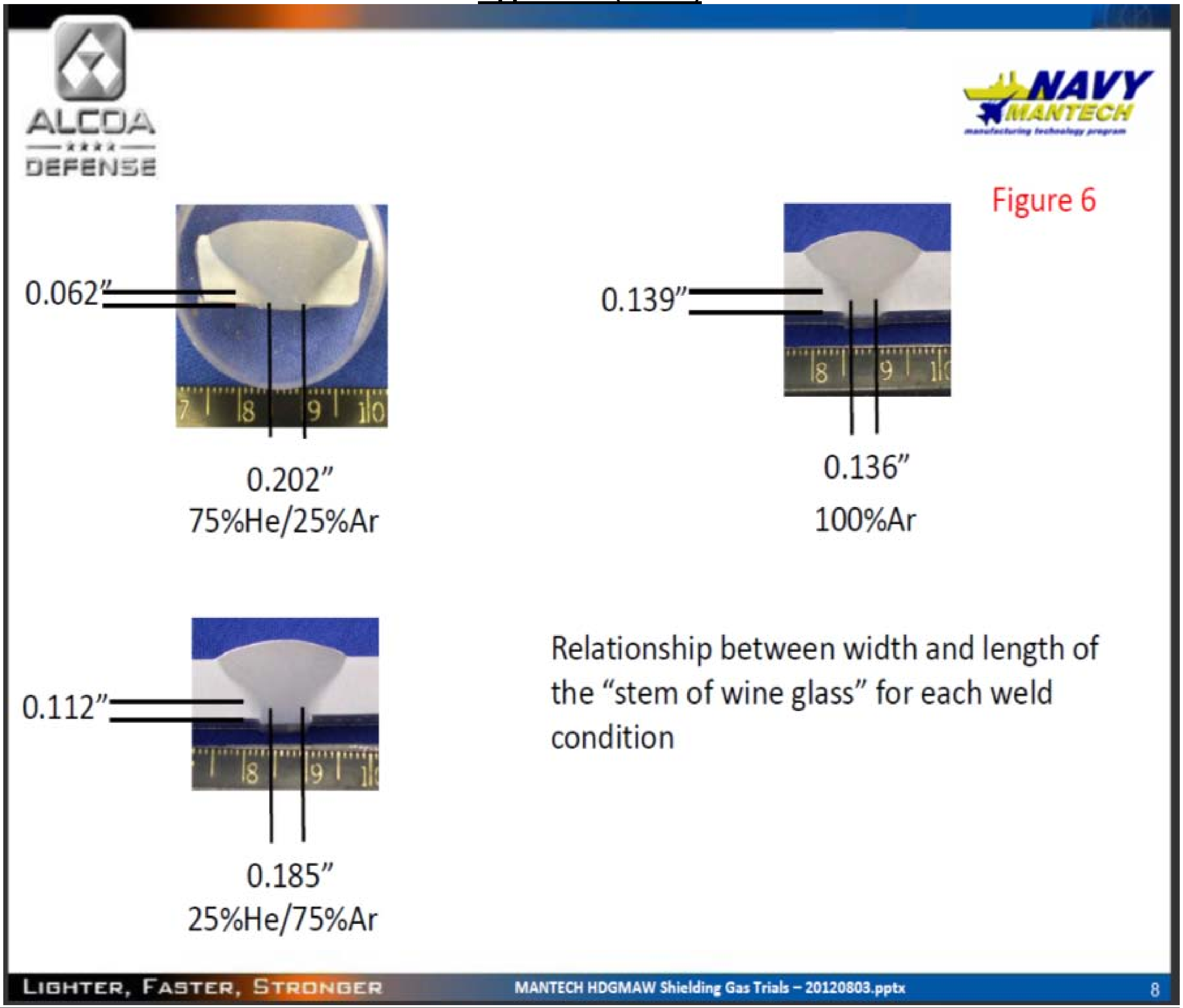


Figure A5-6 – Relationship between width and length of the "stem of wine glass" for each weld condition

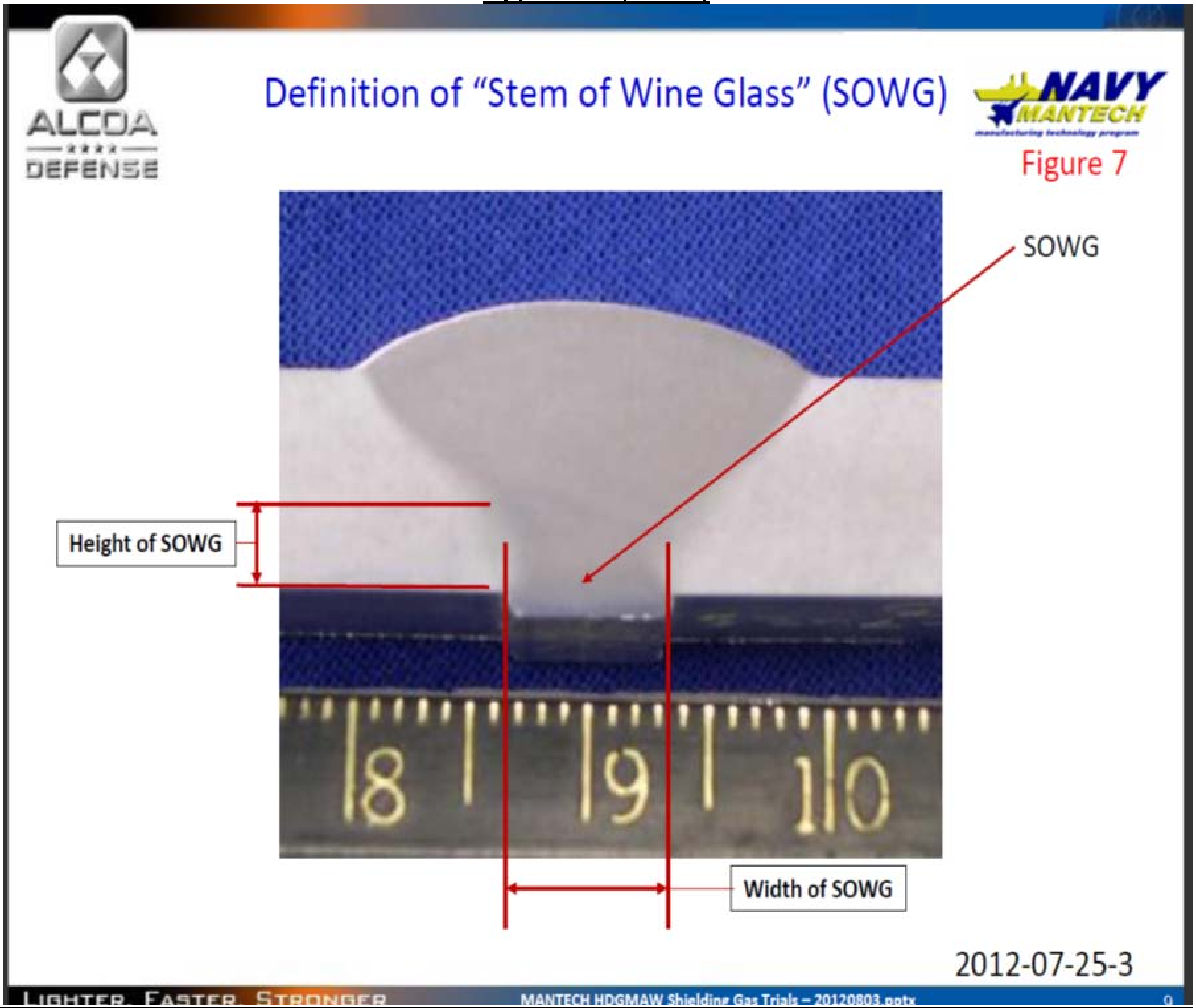


Figure A5-7 – Definition of "Stem of Wine Glass" (SOWG)

Appendix 5 (cont'd)

Results:

1. With no joint gap and no parts offset, the weld produced with the 100% Argon results in a top weld bead width which is **11.5%** narrower than the weld produced with the 75% He/25% Ar mixture and **8%** narrower than the weld produced with the 25% He/75% Ar mixture (Figures 1, 2 and 3).
2. With no joint gap and no parts offset, the weld produced with the 100% Argon results in a top weld bead height which is **30% higher** than the one produced with the 75% He/25% Ar mixture and **14%** higher than the weld produced with the 25% He/75% Ar mixture (Figures 1, 2 and 3).
3. With no joint gap and no parts offset, the weld produced with 100% Argon results in a "stem of wine glass" ("SOWG") (Figure 7), which is **49%** narrower than the SOWG produced with the 75% He/25% Ar and **36%** narrower than the weld produced with the 25% He/75% Ar gas mixture (Figures 1, 2 and 3).
4. With no joint gap and no parts offset, the height (or length) of the SOWG, at the lower part of the weld nugget, of the weld produced with the 100% Argon is **124%** longer than the SOWG of the weld produced with the 75% He/25% Ar and **24%** longer than the SOWG of the weld produced with 25% He/75% Ar gas mixture (Figures 1-3 and 6).
5. The three welds produced with 100% Argon, 75% He/25% Ar and 25% He/75% Ar were geometrically consistent, radiographically sound and passed the Face and Root bend tests.

Conclusions and Recommendations:

1. The welds produced with the three gas mixtures were geometrically consistent and metallurgically sound.
2. Even though welding with the 100% Argon has demonstrated that it may be feasible to use it for welding Square-Butt joints between the 8mm thick 5083/5086 parts with the High Deposition Gas Metal Arc Welding (HDGMAW) process, at this point Alcoa does not recommend to carry out the rest of the program with this shielding gas, for the following reasons:
   A. As the aforementioned results show, the use of 100% Argon results in narrower weld nuggets and higher and narrower top weld beads, which will make it more difficult to meet some of the present weld requirements (e.g. <0.090in. Top weld bead height, etc.) in production.

Appendix 5 (cont'd)

B. The narrower (3.4mm, 0.136in.) and longer (3.5mm, 0.139in.) SOWG formed with the 100% Argon (Figures 3 and 6), at the lower parts of the welds, will be less capable of accommodating variations in joint gaps and/or combinations of joint gap & parts offsets, in production. Even though preliminary trials with the 100% Argon gas resulted in sound welds when welding with 1mm (0.040in.) and 2mm (0.080in.) joint gaps (Figures 4 and 5), at this point , Alcoa can not guarantee that welding with this shielding gas will guarantee sound welds with larger joint gaps and parts offsets. Alcoa believes that for production the HDGMAW process should be developed and used with maximum forgiveness (or tolerance) to variations in the parts tolerances, which will directly affect how these tolerances stack-up at the the Square-Butt joints.

C. To meet the primary goal of Phase I of this program, which is to demonstrate the feasibility and applicability of the HDGMAW process to welding Square –Butt joints between 8mm thick 5083-H116 plates, **Alcoa recommends to use the 25% He/75% Ar gas mixture** which will use significantly less Helium than the original 75% He/25% Ar mixture, but will still provide an extra degree of forgiveness to welding with the process in production.

D. Once Phase I of this program is successfully completed and a more thorough understanding of the HDGMAW process and its use are gained, the two shipyards participating in this program may decide to further investigate the use of 100% Argon with this welding process.

3. In summary we recommend the use of the **25% He/75% Ar** gas mixture throughout Phase I of this program.

Telecom Topic: Welding Gas Selection for ManTech HDGMAW Program **Date: August 07, 2012**

Minutes by: Bill Grassel

Attendees Invited:

ABS

Jon Fallick

ALCOA

Phil Gacka, Bill Grassel, Dan Myers, D. J. Spinella, Israel Stol, Kyle Williams

Austal

Amy Dewise, Mike Webster

MMC

Tracey Coveyou, Charlie Jackson

SCRA / Schaffran Inc.

Bob Schaffran

Warren Southerland

Attendees Present: All except Myers, Dewise, Webster, Coveyou, Jackson

Objective

- Review Alcoa results from welding with different welding gas compositions and select the welding gas to use for further HDGMAW development.

Minutes

Results from Alcoa welding trials summarized in the 2012-08-03 presentation prior to the meeting were reviewed. These trials were conducted on 0.313" (8 mm) thick 5083-H116 plate being used for HDGMAW development. Welding gas compositions tested include:

- 75% He, 25% Ar
- 25% He, 75% Ar
- 100% Ar

Differences in the weld nugget geometry when using different shielding gas compositions were discussed. As the percentage of Ar increased, the weld was narrower and the top face reinforcement was higher. These two conditions could be detrimental to use of this technology because:

- narrower welds would require more exact plate positioning, and
- the top face reinforcement could exceed targets specified in the Weld Attributes document developed for this program

Welding speed with the 75% and 100% Ar gas was also about 10% less than the 75%He, 25% Ar mixture. Other than this, it was noted that the weld quality obtain with each gas composition was very similar. All produced acceptable AWS face and root bend test results.

On the negative side, all compositions resulted in a backside weld condition that would not have a consistent re-entry angle larger than 90°. This was related to the 1inch wide groove (recess) in the back-up bar that was intended to provide maximum lateral positioning flexibility in production set-ups.

Decisions Reached After Presentation Review and Subsequent Discussion

- Alcoa will use 100% Argon as the HDGMAW shielding gas in further process work.
- A bevel will be added to the top side of one or both plates to control the face side weld reinforcement height and geometry

Attempts will be made to use a recess geometry in the backup bar which will help "scalp" the weld bead on the backside so it conforms to the targeted requirement of the re-entry angle of >90°. Backside weld grinding may be required if the backing bar recess geometry solution does not accommodate a wide enough range to meet production fit-up capabilities.

Appendix 6

ManTech Temporary Weld Backing Trials – September 4, 2012 Team Summary

Objective: Evaluate the influence of the temporary weld backing groove on the geometry of the weld root side melt-through profile.

Materials and Joint Configuration
Base Metal: 5083–H116, 0.313 in. thick
Joint Type: Single Vee butt joint, 90° included angle, 0.125 in. depth of preparation, 0.0 in. root opening
Electrode / Filler: ER5183 0.063 in. diameter
Shielding Gas: 100% Argon

Backing Bars Tested
Ceramic – Groove 0.25in, Radius x 0.040in deep
Anodized Aluminum – Groove 1in wide x 0.040in deep

Conditions Evaluated
Case 1 - Ceramic – R0.25x0.040 – Zero Gap & Zero Mismatch
Case 2 - Ceramic – R0.25x0.040 – Zero Gap & 0.040in. Mismatch
Case 3 – Anodized Al – 1.0x0.040 – Zero Gap & Zero Mismatch

All three cases: cross-sections taken near start & end of weld

Appendix 6 (cont'd)

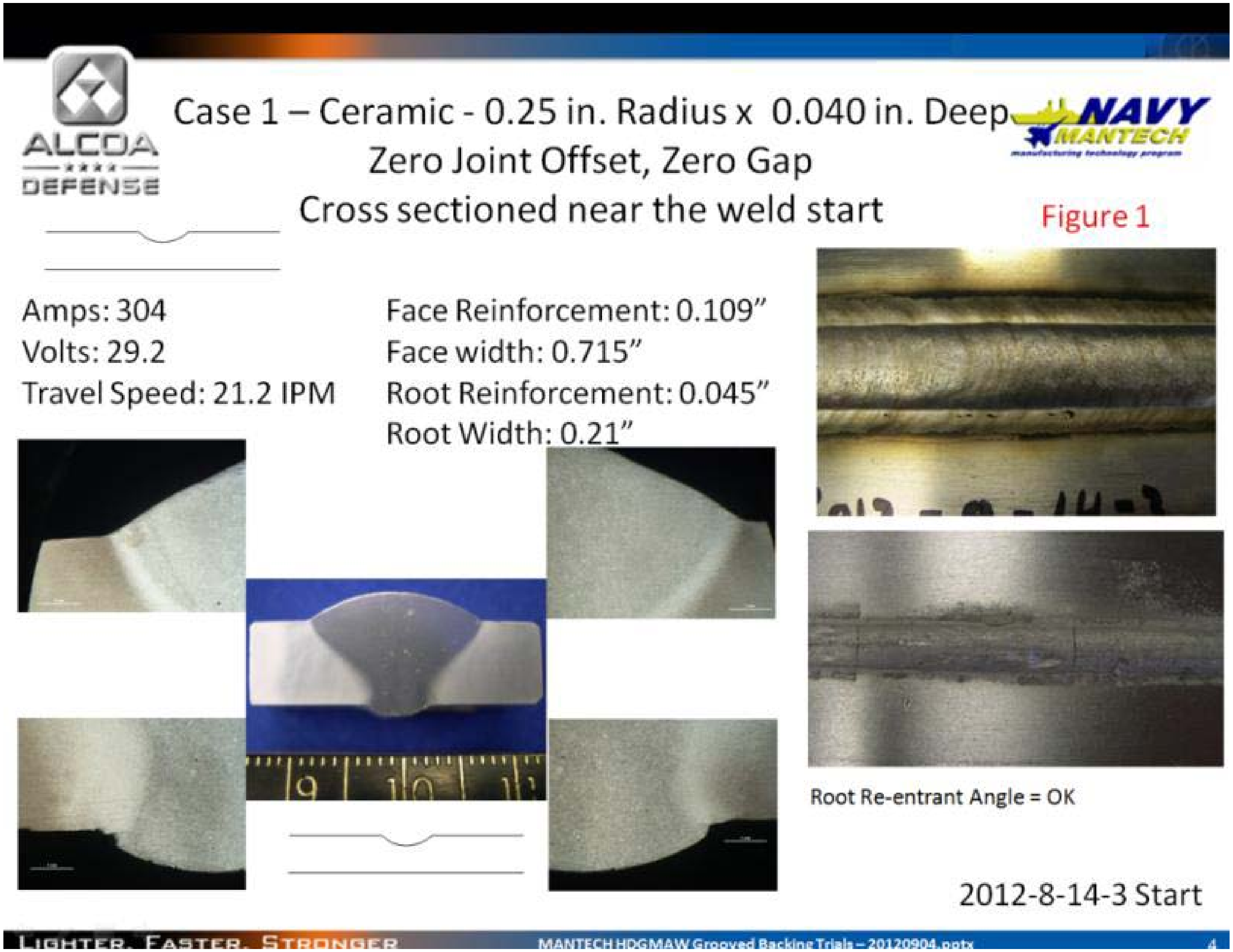


Figure A6-1 – Case 1 – Ceramic – 0.25 in. Radius x 0.040 in. Deep Zero Joint Offset, Zero Gap Cross sectioned near the weld start

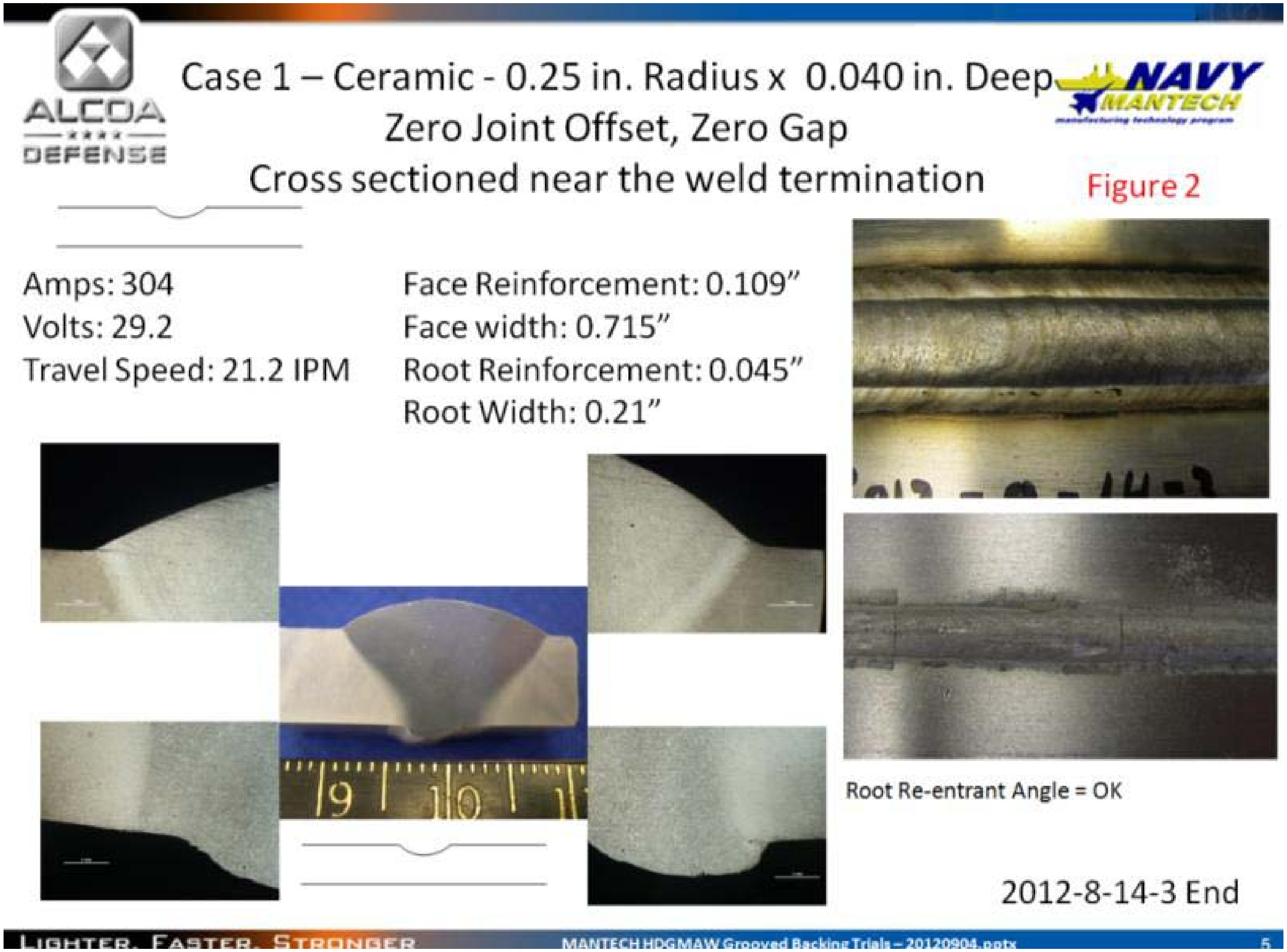


Figure A6-2 – Case 1 – Ceramic – 0.25 in. Radius x 0.040 in. Deep Zero Joint Offset, Zero Gap Cross sectioned near the weld termination

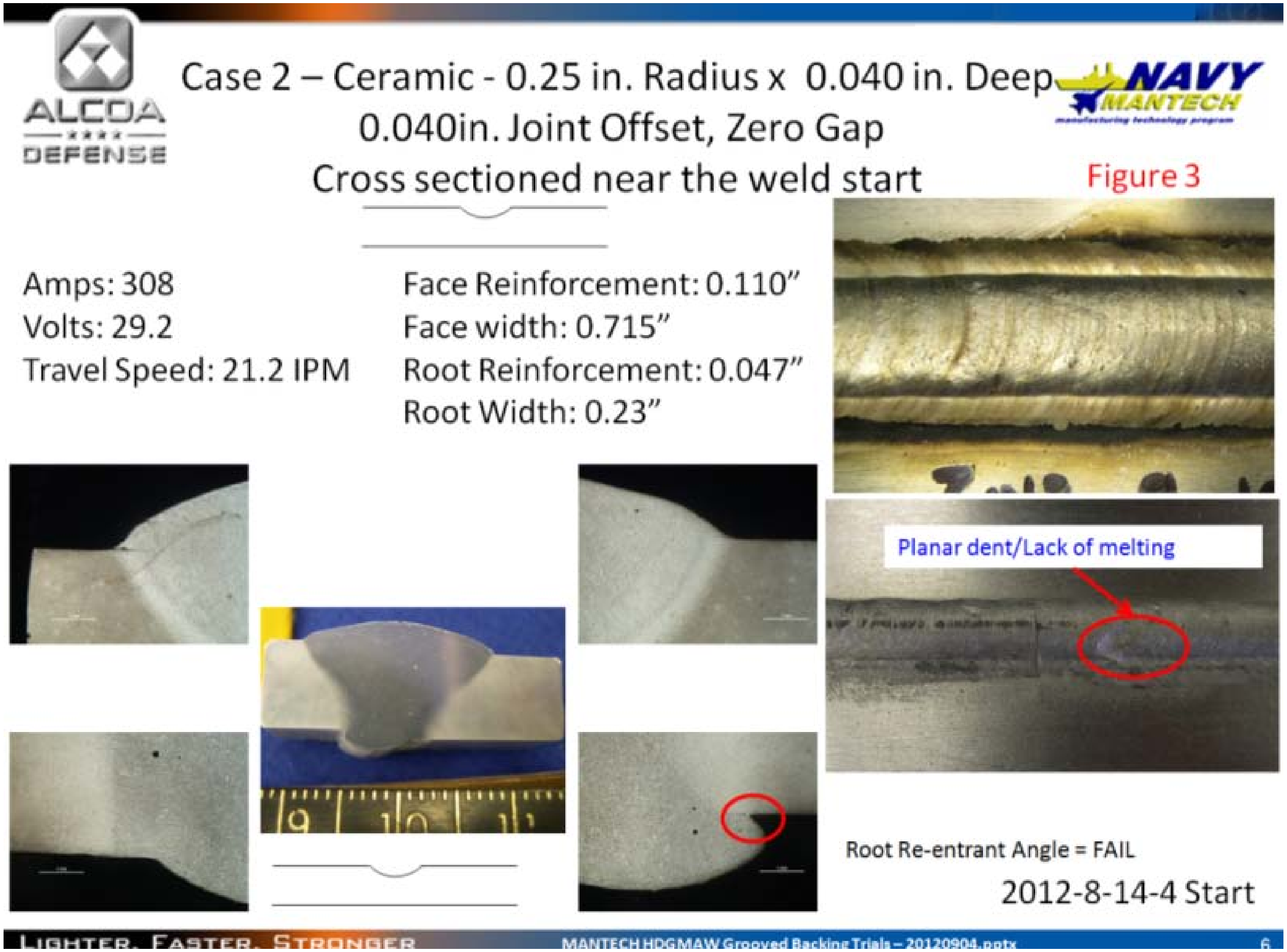


Figure A6-3 – Case 2 – Ceramic – 0.25 in. Radius x 0.040 in. Deep 0.040 in. Joint Offset, Zero Gap Cross sectioned near the weld start

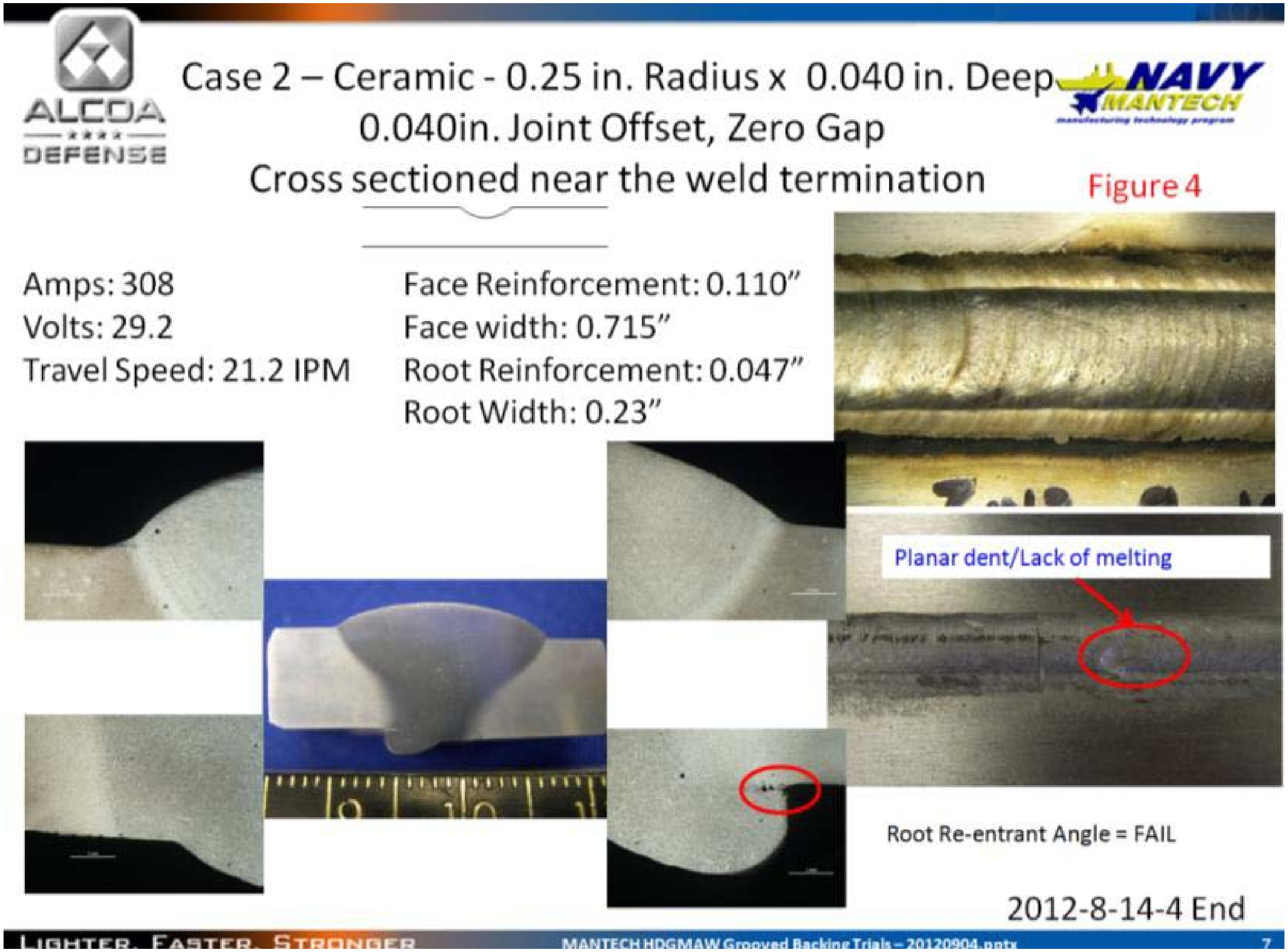


Figure A6-4 – Case 2 – Ceramic – 0.25 in. Radius x 0.040 in. Deep 0.040 in. Joint Offset, Zero Gap Cross sectioned near the weld termination

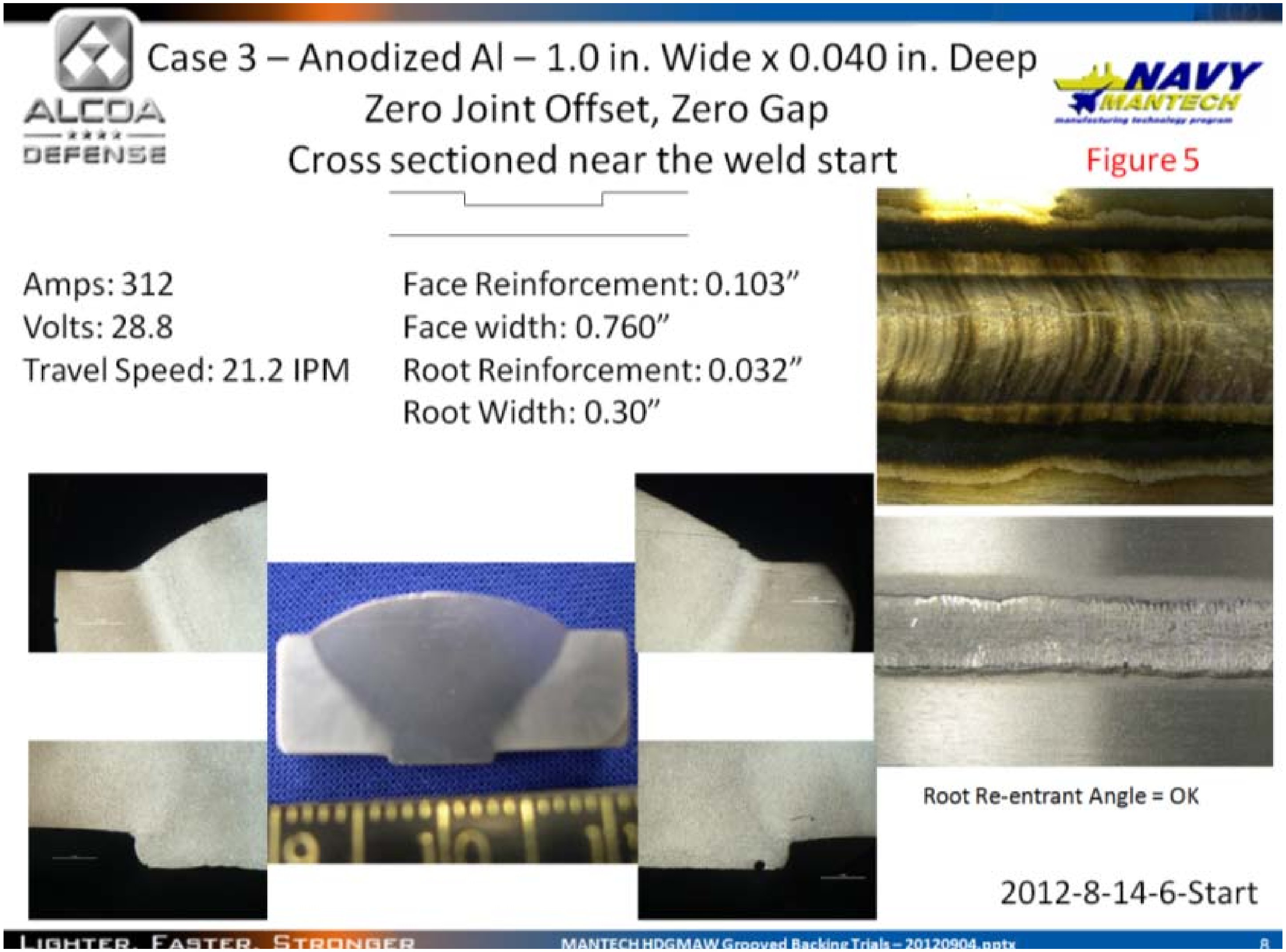


Figure A6-5 – Case 3 – Anodized Al – 1.0 in. Wide x 0.040 in. Deep Zero Joint Offset, Zero Gap Cross sectioned near the weld start

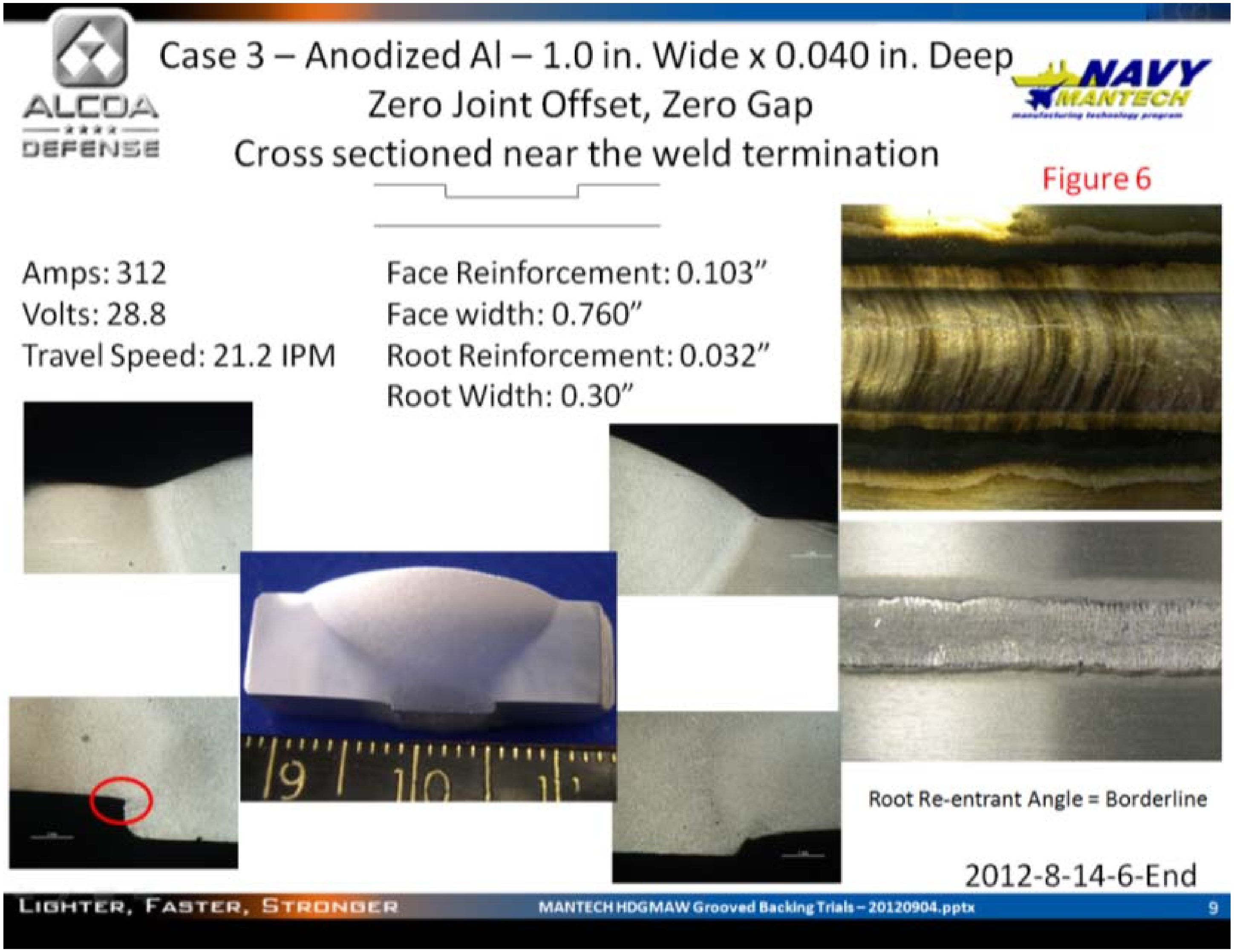


Figure A6-6 – Case 3 – Anodized Al – 1.0 in. Wide x 0.040 in. Deep Zero Joint Offset, Zero Gap Cross sectioned near the weld termination

Results:

1. The use of the "contoured" recess in a temporary backup (Figures 1-4) can produce re-entrant angles >90^0 , which meet the present requirement for the back side of the welds produced with the HDGMAW process between the 0.313in. thick Square Butt joints .
2. A comparison between Figures 1 and 2 shows that the re-entrant angles on the back sides of the welds, vary from near the weld start and weld termination points, despite the fact that the joint gap between their edges and the offset between them were maintained close to 0.0in. This variation in re-entrant angles on the back sides of the HDGMA welds is made more pronounced with a 0.040in. offset between the parts (Figure 3 versus 4).
3. When welding with the "contoured" recess in a temporary backup (Figures 1-4), Alcoa has observed that the back sides of the welds had intermittent "planar dents" and occasional short (e.g. 0.04in. long) lack of melting (i.e. undercut like) along the toes of the welds (i.e. undercut like), which are suspected to have been formed by periodic pressure build-up within the channel formed between the "contoured" recess in the backup and the backside of the parts being welded. This phenomenon is not unusual when welding with recessed backup bars whose cross-sectional area are too small for efficient venting of pressure build up directly under the solidifying soft back sides of welds. There is a potential for a formation of an unacceptable back bead geometry due to this phenomenon (i.e. back concavity).
4. Similar to the back sides of welds produced with the "contoured" recess in a temporary backup, reported in the two aforementioned results, the re-entrant angles vary from near the weld start and weld termination points when using the 1.0in. wide and 0.040in. deep recess in a temporary backup (Figure 5 versus 6).

Conclusions and Recommendations:

1. The "sculpting" of the back sides of welds into the required re-entrant angles of >90^0 with the aid of "contoured" (Figures 1-4) or "Squared" (Figures 5 and 6) recesses in temporary backups, cannot be consistently achieved in production with the HDGMAW process. The variations in parts offsets which are expected to be encountered in production make the consistent control over the re-entrant angles of the back sides of HDGMAW welds impossible.
2. For maximum forgiveness to lateral placement and misalignment of the recessed backups with the Square-Butt joints in production and adequate venting of gases and release of the resultant pressure in the channels formed between the recesses and back sides of parts, Alcoa recommends the use of backups with 1in. wide and 0.040in. deep "squared" recesses (Figures 5 and 6). This pressure build up stems from volatization and/or evaporation of contaminants on the parts and/or recessed backup bars. The final dimensions (i.e. width and depth) of the "squared" recess will need to be re-visited once longer joints are welded (e.g. 5ft., 10ft. 40ft.) to ensure adequate pressure venting through these channels.
3. Regardless of the geometry of the grooved temporary back-up, it is not expected that to meet the root side re-entrant angle requirement consistently with the HDGMAW process.
4. The HDGMAW process will have to include an inspection step of the back bead. If the re-entrant angle requirement is not met, post weld grinding will be done to meet the criteria.
5. Next, attempts will be made to develop an approach and welding procedure that will ensure that the height of the top weld reinforcement meets the <0.090in. requirement when welding with pure argon.

Appendix 7

ManTech HDGMAW Weld Face Reinforcement Trials - September 18, 2012 Presentation

Objective: Evaluate the influence of weld joint preparation, weld procedure, and depth of temporary weld backing recess (groove) have on the height of the weld face reinforcement.

Materials & Joint Configuration:
Base Metal: 5083–H116, 0.313 in. thick
Joint Type: Single Vee butt joint, 90 degree included angle with various depth of preparation, 0.0 in. root opening
Electrode / Filler: ER5183 0.063 in. diameter
Shielding Gas: 100% Argon

Conditions Tested

	Conditions				
	1	**2**	**3**	**4**	**5**
Depth of Edge Prep (in.)	0.160	0.160	**0.125**	**0.080**	0.080
Depth of Groove (in.)	0.040	0.040	**0.080**	**0.040**	**0.080**
Weld Travel Speed (in/min)	21.2	**23.8**	21.2	21.2	21.2

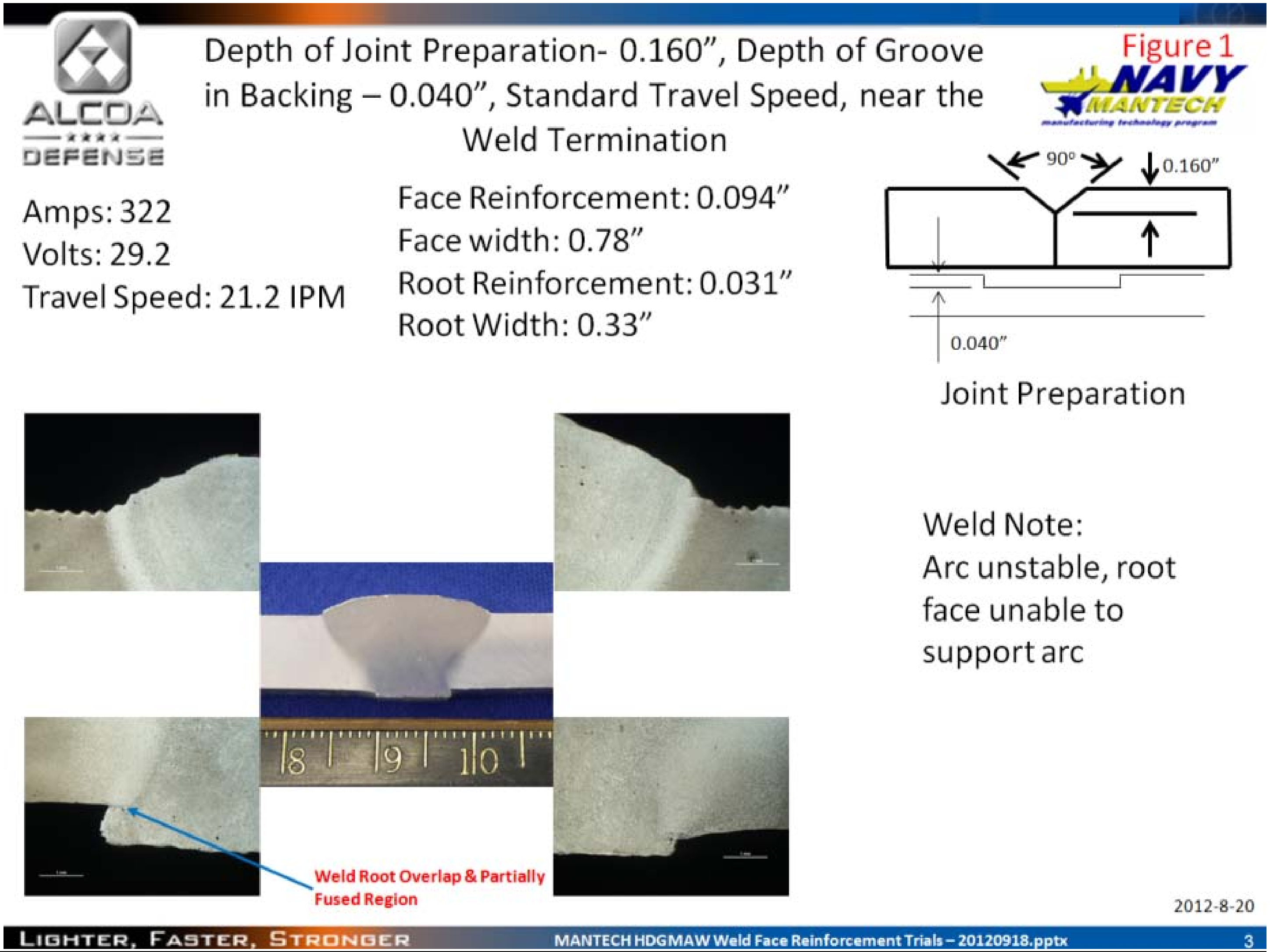


Figure A7-1 – Depth of Joint Preparation – 0.160", Depth of Groove in Backing – 0.040", Standard Travel Speed, near the weld termination

Appendix 7 (cont'd)

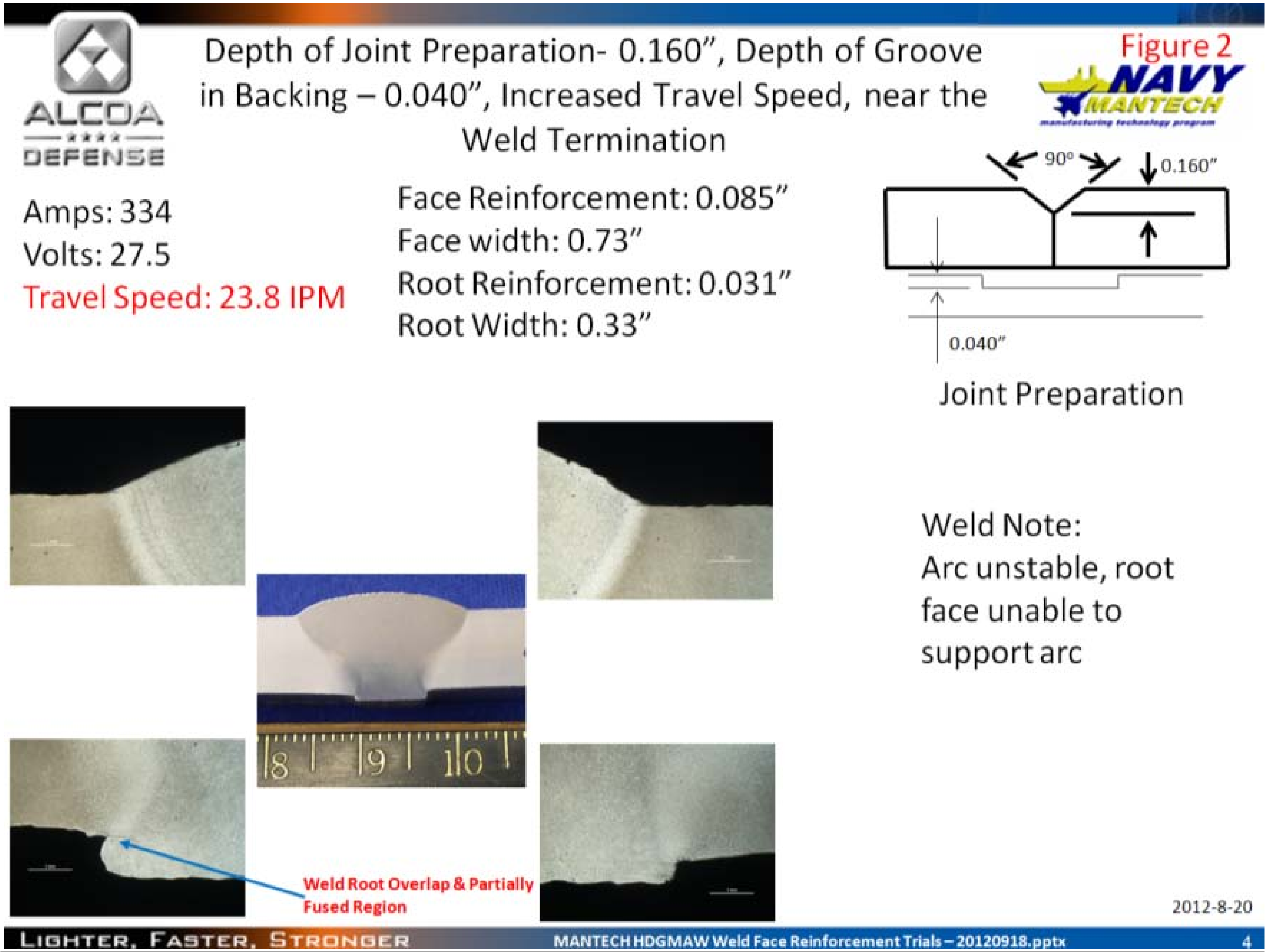


Figure A7-2 – Depth of Joint Preparation – 0.160", Depth of Groove in Backing – 0.040", Increased Travel Speed, near the Weld Termination

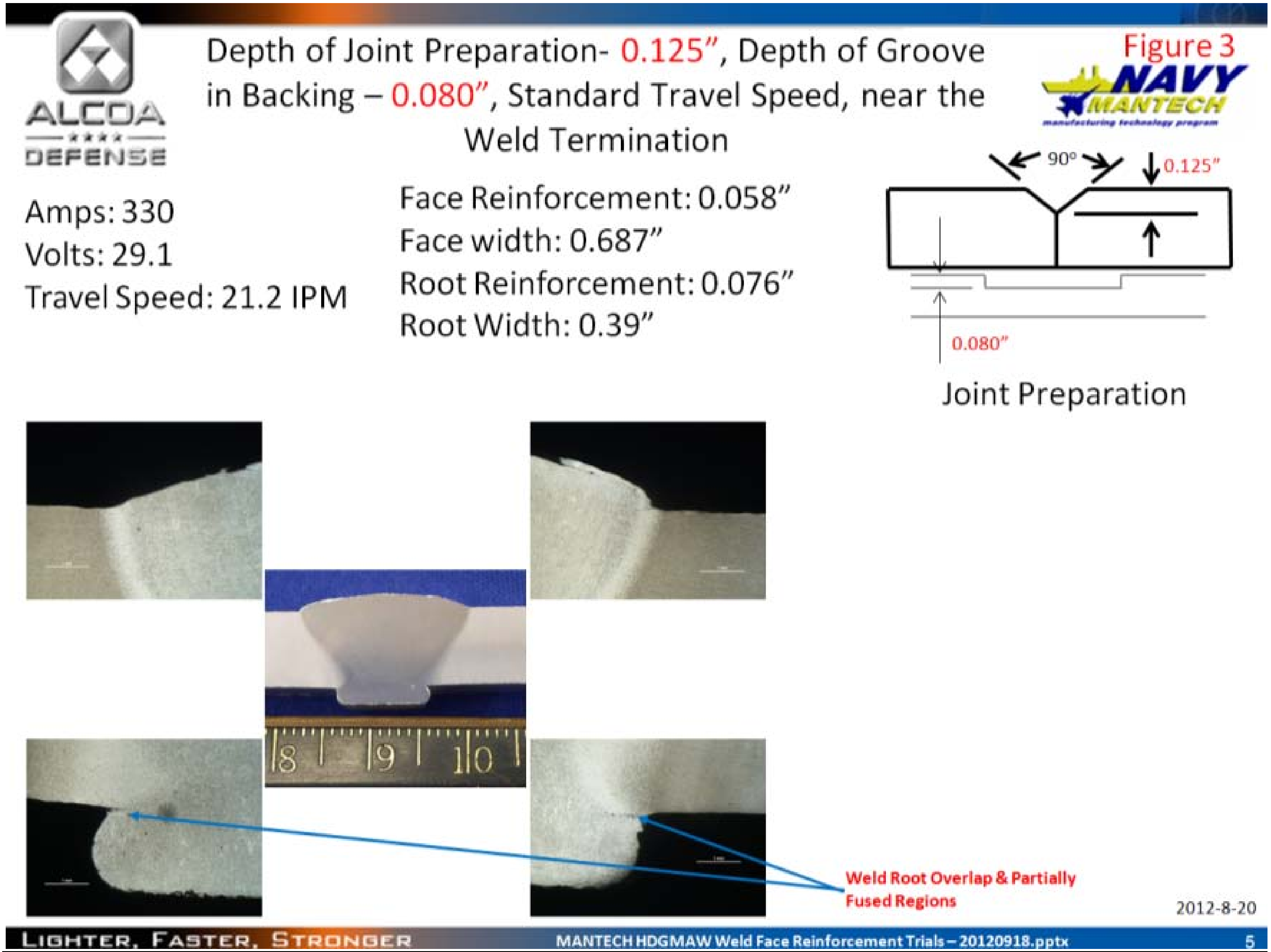


Figure A7-3 – Depth of Joint Preparation – 0.125", Depth of Groove in Backing – 0.080", Standard Travel Speed, near the Weld Termination

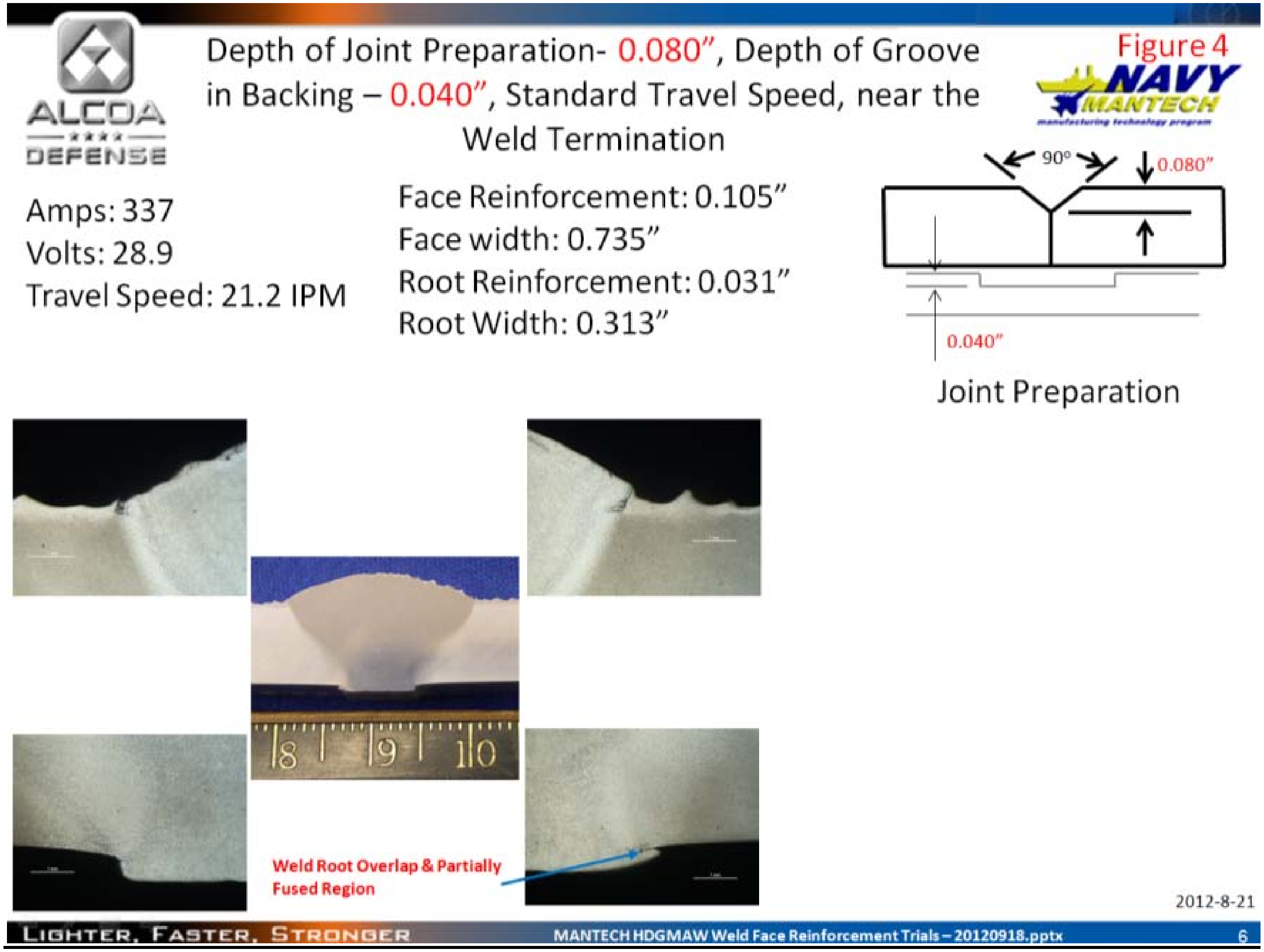


Figure A7-4 – Depth of Joint Preparation – 0.080", Depth of Groove in Backing – 0.040", Standard Travel Speed, near the Weld Termination

Appendix 7 (cont'd)

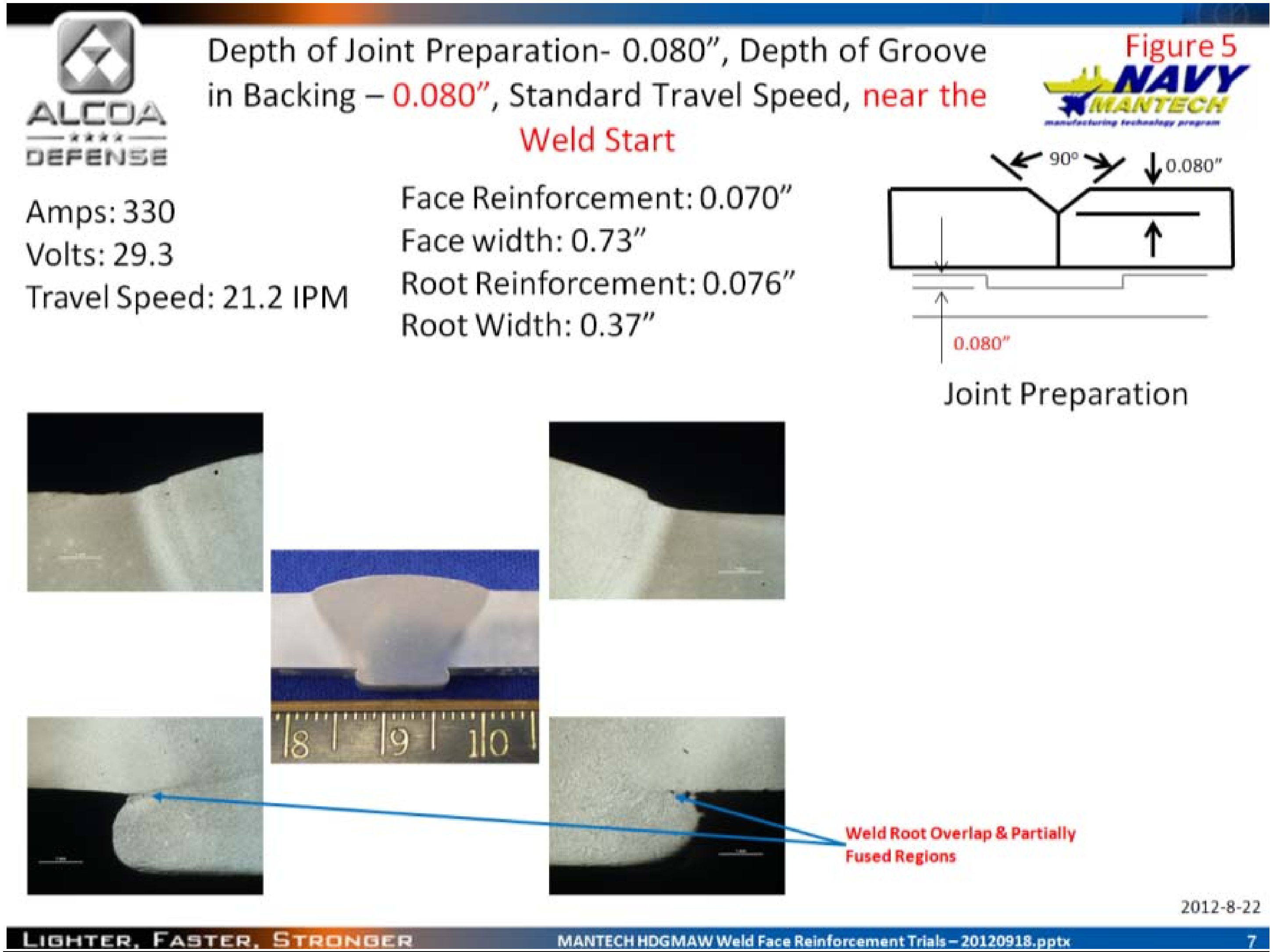


Figure A7-5 – Depth of Joint Preparation – 0.080", Depth of Groove in Backing – 0.080", Standard Travel Speed, near the Weld Start

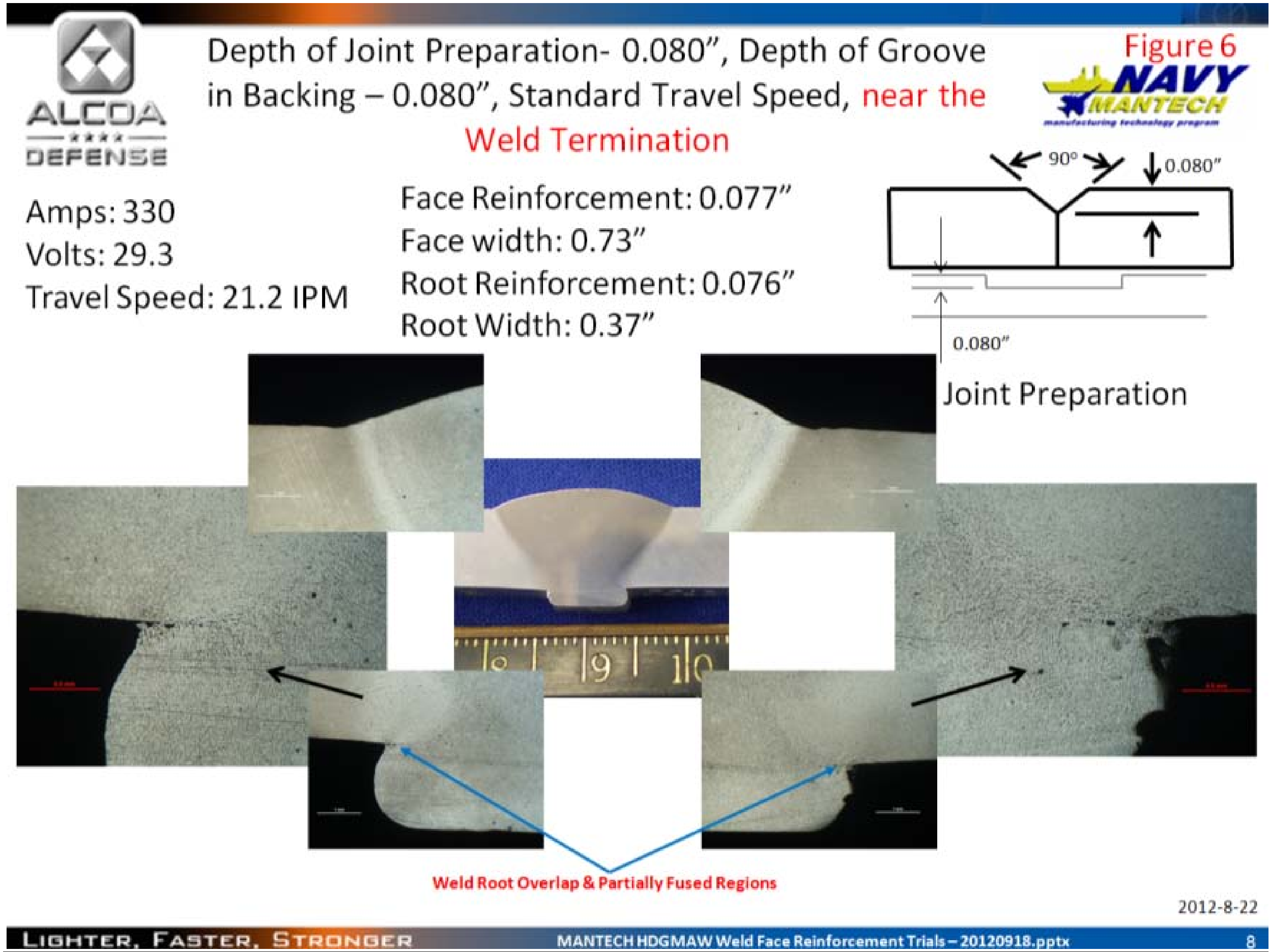


Figure A7-6 – Depth of Joint Preparation – 0.080", Depth of Groove in Backing – 0.080", Standard Travel Speed, near the Weld Termination

Results:

According to Figures 1 through 6:

1. The combination of 0.160in deep top Vee joint preparation, 0.040in deep temporary weld backing groove and standard welding parameters (Figure 1) results in:
   - A. An unstable arc.
   - B. A height of weld face reinforcement of 0.094in, which narrowly exceeds the 0.090in maximum allowed height, agreed on between John Fallick of ABS and Israel Stol.
   - C. A partially fused region on the back side of the weld, where the molten metal has rolled-over against the back face of one of the parts being welded, to form an overlap at the edge of the root reinforcement.
2. Increasing the welding speed of travel from the standard 21.2 ipm to 23.8 ipm with the same 0.160in deep top Vee joint preparation and 0.040in deep temporary weld backing groove, as used in the first combination (Figure 1), according to Figure 2 results in:
   - A. A 0.085in high weld face reinforcement, which meets the <0.09in requirement.
   - B. An unstable arc.
   - C. Formation of an overlap at the edge of the weld root reinforcement and a partially fused region between the root of the weld and one of the parts being welded.
3. The combination of 0.125in deep top Vee joint preparation, 0.080in deep temporary weld backing groove and standard welding parameters (Figure 3) results in:
   - A. A 0.058in high weld face reinforcement of which meets the <0.090in height requirement.
   - B. Two partially fused regions on the back side of the weld, directly under the overlaps at the two edges of the root reinforcement.
4. The combination of a 0.08in deep top Vee joint preparation, 0.040in deep temporary weld backing groove and standard welding parameters (Figure 4) results in:
   - A. A 0.105in high weld face reinforcement, which exceeds the <0.090in height requirement.
   - B. A partially fused region on the back side of the weld, directly under the overlap where the molten metal has rolled-over against the back face of one of one of the parts being welded.

Results, Cont.

5. The combination of a 0.08in deep top Vee joint preparation, 0.080in deep temporary weld backing groove and standard welding parameters (Figures 5 and 6) results in:
   A. A 0.07in high weld face reinforcement near the weld start and 0.07in near the weld termination, both of which are comfortably below the <0.090in height requirement.
   B. Two partially fused regions on the back side of the weld, directly under the overlaps where the molten metal has rolled-over against the back faces of each of the parts being welded.

Conclusions and Recommendations:

1. The HDGMAW process is capable of producing welds between 0.33in thick 5083-H116 parts through closed (i.e. no joint gap) Square-Butt joints, which are consistently sound and meet most but not all of their geometric requirements. Based on recent work, it is impossible to produce welds that consistently meet the >90^0 re-entry angle of the root side of these welds. However, through a specific combination of top Vee joint geometry (i.e. depth and angle), HDGMAW parameters and groove depth in temporary weld backing bars, it is possible to meet the <0.090in height requirement of the top weld reinforcement, while meeting all other weld quality requirements except the > 90^0 re-entry angle at the weld root.
2. In this study all the combinations of top Vee geometry, HDGMAW parameters, and groove depth in the temporary weld backup bar, resulted in formation of very shallow (i.e. superficial <0.009in thick) and narrow (<0.040in wide) partially fused regions between the rolled over edge portions of the weld roots and the back face(s) of the parts being welded (Figures 1 though 6). These partially fused regions on the back sides of the welds, were closely associated with the presence of overlaps between the weld root and back face(s) of the parts being welded.
3. The overlaps and partially fused regions on the back sides of welds become more pronounced as the depth of the grooves in the temporary weld backing bar increase (e.g. Figures 5 and 6 versus 2).

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Conclusions and Recommendations, Cont.

4. When establishing the most desirable combination of top Vee joint preparation, HDGMAW parameters, and groove depth in the temporary backup bars designed to meet the <0.090in required top weld reinforcement height and weld quality, it is necessary to take into account the following factors:
   A. Arc stability, to a large degree, is determined by the amount (i.e. thickness) of molten material underneath it. This is the reason~~,~~ why the joints with the deeper (e.g. 0.160in) (Figures 1 and 2) top Vee grooves became less stable than the joints with the shallower top grooves (Figures 3-6).
   B. Height of the top weld reinforcement and its two re-entry angles with the top surfaces of the parts being welded.
   C. The extent (i.e. depth and width) of the partially fused regions in the back faces (i.e. weld root side) of the parts being welded (Figures 1 through 6).
   D. Required weld quality (i.e. porosity, lack of fusion, concavity, etc.).
   E. How practical would it be to implement in production.
5. Based on the results of this study, the combination of geometry of the top Vee joint (i.e. 0.080in deep) preparation, HDGMAW parameters (i.e. standard), and depth of groove (i.e. 0.08in) in the backup temporary bar presented in Figures 5 and 6 affords the most practical approach for meeting the required <0.090in top weld reinforcement height and weld quality. However, for structurally (e.g. fatigue, strength/fatigue) critical areas, the re-entry angles of the weld roots produced with this approach will have to be ground-blended into an 180^0 re-entry angle with the two welded parts. Because the depth of the partially fused region on the back side (i.e. root) of the welds is minimal (e.g. <0.009in.) and its width is less than 0.040in. (Figures 5 and 6), the grind-blending operation of the weld root edges will readily remove these partially fused regions.
6. Following a few additional confirmatory HDGMA welding trials, in the very near future Alcoa will present to the ManTech team several practical options for meeting the required <0.090in top weld reinforcement height and weld quality in production. Once the preferred option is chosen , Alcoa will launch the planned welding trials to establish the Parametric Envelope of the HDGMAW process with this Square-Butt joint.

Appendix 7 (cont'd)

Based on data presented in Appendix 7, the selected groove recess to continue HDGMAW process development was 1" wide and 0.05" deep. The 1" width facilitates aligning the center of the backing bar recess with the weld seam. The 0.05" deep recess provided the best overall performance considering weld root geometry, weld face height, and arc stability.

Appendix 8

Summary of Options for Welding with the High Deposition Gas Metal Arc Welding (HDGMAW) Process Under the ManTech Program, September 19, 2012 Presentation

Purpose: Present the options for welding with the High Deposition Gas Metal Arc Welding (HDGMAW) process, as affected by the shielding gas, dimensions of the top vee groove and depth of the recessed removable backing bar. Down select the preferred option based on the weld quality requirements and production process feasibility.

Options Evaluated:

Option 1:

100% Ar

Depth of Vee Groove: 0.080''

BackUp Bar Depth: 0.080''

Reground Back Side to 180 degree

2012-08-22-4

Option 2:

100% Ar

Depth of Vee Groove: 0.120''

BackUp Bar Depth: 0.030''

Reground Back Side to 180 degree

2012-09-06-2

Option 3:

25% He

75% Ar

Depth of Vee Groove: 0.080''

BackUp Bar Dept: 0.030''

Reground Back Side to 180 degree

2012-09-06-1

Option 4:

75% He

25% Ar

Depth of Vee Groove: 0.080''

BackUp Bar Depth: 0.030''

Reground Back Side to 180 degree

2012-09-06-3

Appendix 8 (cont'd)

Figure A8-1 – Option 1: 2012-08-22-4, 100% Ar, 0.080" Vee Groove, 0.080" Backup Bar Depth, Reground Back Side to 180 Degrees

Appendix 8 (cont'd)

Figure A8-2 – Option 2: 2012-09-06-2, 100% Ar, 0.120" Vee Groove, 0.030" Backup Bar Depth, Reground Back Side to 180 Degrees

Figure A8-3– Option 3: 2012-09-06-1, 75% Ar/25% He, 0.080" Vee Groove, 0.030" Backup Bar Depth

Figure A8-4 – Option 4: 2012-09-06-3, 75% He/25% Ar, 0.080" Vee Groove, 0.030" Backup Bar Depth

Appendix 8 (cont'd)

Summary Table

	Option 1	Option 2	Option 3	Option 4	Note
Inputs					
Depth of Edge Prep (in.)	0.080	0.120	0.080	0.080	
Depth of Groove (in.)	0.080	0.030	0.030	0.030	
%Ar	100	100	75	25	
Outputs					
Face Reinforcement (in.)	0.076	0.110	0.100	0.074	Max = 0.090
Root Reinforcement (in.)	0.076	0.023	0.029	0.031	Max = 0.090

Results:

1. It is not possible with any of the four (4) options to simultaneously achieve the required <0.090" height of the face (top) and root (back) sides of the weld reinforcement and >90° re-entry angles. This necessitates a "compromise" choice of which of the four (4) options to employ with the HDGMAW process.

2. While the use of shallower (i.e. 0.030") recesses in the removable backup bars tends to increase the re-entry angles on the root side of the welds above the >90° required re-entry angle, when welding with 75%He/25%Ar and 25%He/75%Ar gas mixtures (Refer to Options 3 and 4), welding with pure Argon tends to yield steeper re-entry angles (Refer to Option 2). Based on previously reported results, which demonstrated the difficulty of achieving consistent re-entry angels on the root side from side-to-side and along welds, we have concluded that the control over the re-entry angles on the root sides of welds is not consistently achievable with any shielding gas.

3. The only two options that "comfortably" met the <0.09" required top weld bead reinforcement height are Option 1, which was produced with pure Argon and Option 4, which was produced with the 75%He/25%Ar mixture.

4. Close (250-400x) metallographic examination of representative cross-sections of the welds produced with the four (4) options, showed that with the exception of the sharp re-entry angles of Option 1, the root sides of the four welds were soundly fused to the back sides of the parent metals. This was consistent with the metallographic examination of all the welds that were previously produced and reported. This was a strong and encouraging indication that the roots of the welds produced with the four welding options can be re-ground to be nearly flush with the back sides of the parent metals, without grinding excessively deep into them (Refer to the re-ground areas at the back side of the weldments produced with Options 1-4).

Conclusions and Recommendations:

1. Because it is not possible with any of the four (4) options to simultaneously achieve the required <0.090” height of the face (top) and root (back) sides of the weld reinforcements and >90° re-entry angles, a compromise choice must be made from the four (4) options to employ with the HDGMAW process.

2. Unless the <0.090” height requirement of the top weld reinforcement can be relaxed (e.g. to <0.120’’) without compromising performance, the only two options available to meet the present height requirement of the top weld reinforcement are Options 1 and 4.

3. For structurally critical applications the re-entry angles of the roots of the welds will have to be ground to 180° with the welds produced with all four (4) options. To avoid missing un-fused areas between the “roll-overs” of weld roots with <90° re-entry angles it would be preferable to grind the weld roots off flush with the back-sides of the parent metals, with minimal thickness removal of the parts.

4. Based on the aforementioned results and those already reported, we recommend to proceed with the program using the welding conditions of Option 1, for the following reasons:
   A. The welding will be carried out with pure Argon, as preferred by the shipyards.
   B. The use of the 0.080” deep top Vee groove will leave extra land (i.e. un-removed thickness), which, in combination with the molten filler alloy, will provide an extra “cushion” of molten metal to partially absorb the impact of the highly constricted arc. This will become particularly important when the mismatch between the parts will form joint gaps and/or offsets, which may lead to direct arc impingement onto the bottom of the removable recessed backup bar, which in turn could adversely affect the stability of the HDGMA welding operation and the quality of the welds.

5. For lateral forgiveness in the placing of the backup bar and for efficient pressure venting, use removable backup bars with 0.080” deep and 1.0” wide recesses.

6. If necessary modify the nominal welding conditions of Option 1 and geometry of the backup bars, based on the results from the planned welding trials to investigate the parameter operating window.

Option 1 was selected as the set of process parameters to use for further process development:

- 100% argon shielding gas
- 0.08”, 90° bevel on plate edges
- Rectangular backing bar recess, 1” wide by 0.08” deep

These parameters were used to develop the welding speed and welding current operating window for acceptable single pass welding. The welding wire was 1/16” diameter, alloy 5183. The center of this operating window was called the “centroid.” Figures A8-1 and A8-2 summarize the baseline HDGMAW activities.

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Operating Point Evaluation
Initial Process with Ø 1/16" Weld Wire

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- The process operating envelope was investigated, with the objective of obtaining an Operating Point near the centroid of the operating envelope to allow for the most stable operation
- Process variables chosen as the Operating Point were:
  - Current – 328 amps
  - Voltage – 28.9 volts
  - Travel Speed – 22.9 ipm
  - Edge Preparation – Single Vee butt joint, 90 degree included angle with 0.080" depth of preparation
  - Backing Bar Groove Depth – 2mm
  - Filler Wire – 1/16" diameter ER5183
  - Lincoln Power Supply
- Weld Quality Checks
  - Geometry – Passed, except back side reentrant angle
  - Visual Testing – Passed
  - Face Reinforcement – Passed
  - Adequate Penetration
  - X-Ray Testing – Passed
  - TYE & Bends – Passed
- Repeat runs were done (3x)
- This was considered our baseline process

Weld Testing - Process Development – 20121217.pptx 3

Figure A8-5 – Operating Point Evaluation Intial Process with Ø 1/16" Weld Wire

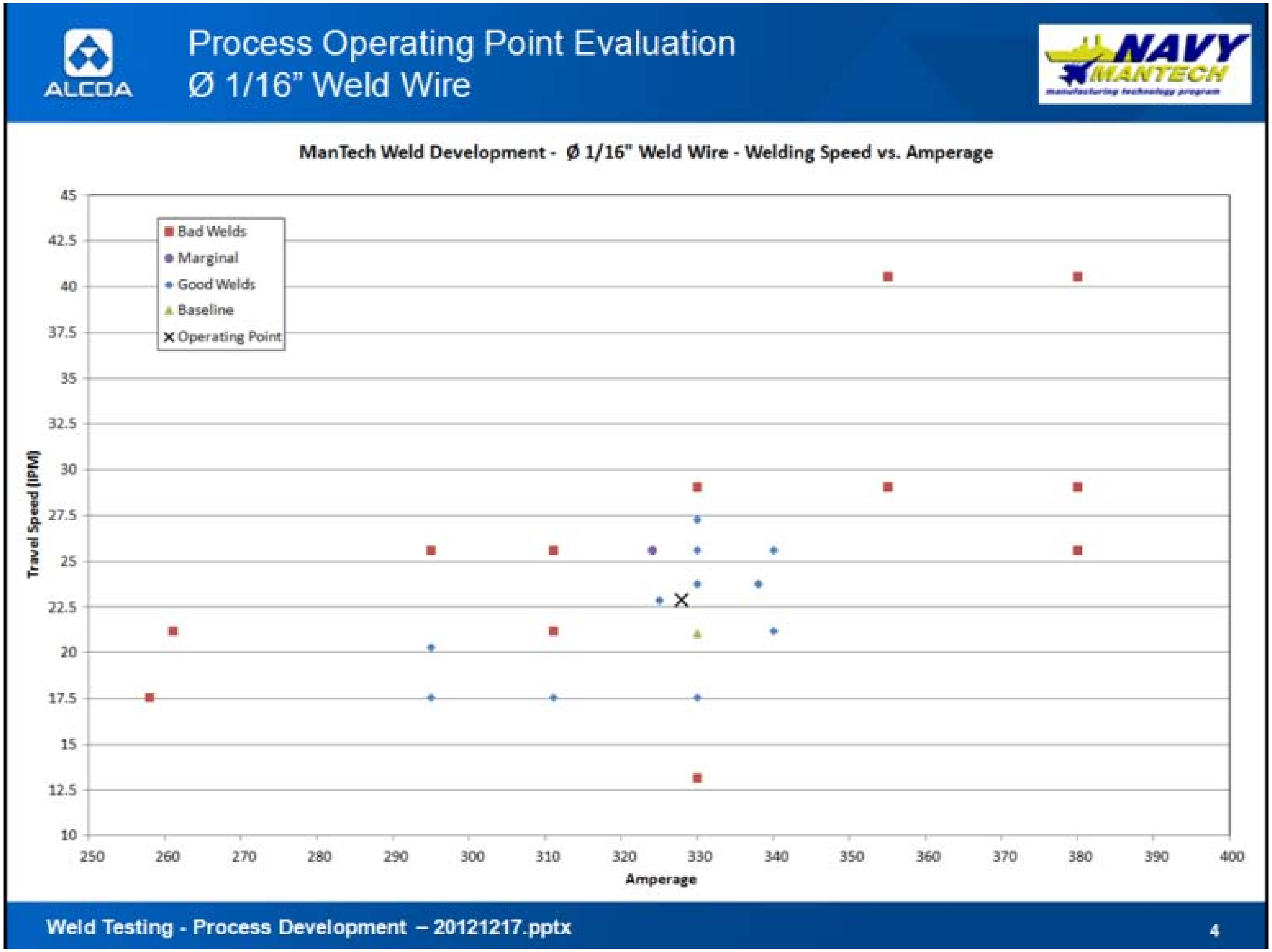


Figure A8-6 – Weld Quality as a Function of Welding Speed & Current

FDH Weld Procedure Specification Summary

Backing:
Type – Temporary – Grooved 1.8mm (0.07") x 25.4mm (1.0")
Material - Anodized Aluminum

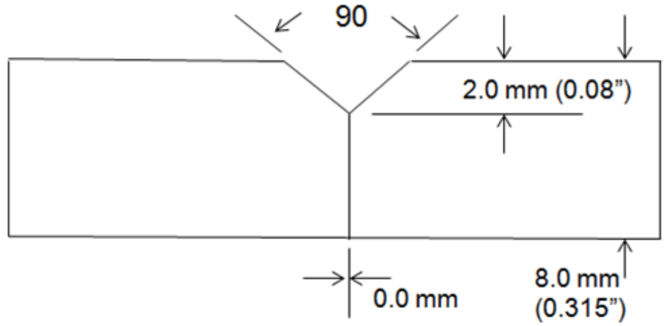
Position:
Flat (1G)

Electrode / Filler:
Alloy – ER5183
Diameter – 0.063 in. (1.5mm)

Shielding Gas:
Argon
Flow Rate: 50 SCFH

Preheat Temperature:
None

Torch Angle:
Work Angle: 0.0
Lead Angle: 15 degrees



GMA Parameters:

Power Supply: Lincoln Power Wave 455M
Wire Feeder: Lincoln Power Feed 25M
Torch/Gun: MK Products Python – Push-Pull
Current Type: Power Mode (Program 40)
Current-Polarity: DC-EP

Average Amperage: 328 Amp
Average Voltage: 28.9 Volt

Travel Speed: 22.9 IPM

Number of Weld Passes: 1

Appendix 10

Ideas to Increase Plate Gap Welding Capability

		Weld Quality Impact				Final Weld System Cost Impact				
Priority	**Option**	**Exceed Top Reinforce Limit**	**Meet TYE**	**Meet Other Quality Requirements**	**Increase Distortion**	**Require Adaptive Fill Control**	**Add Equipment Costs**	**Add Processing Costs**	**Add Consumable Costs**	**Likely Gap Impact (Low-Medium-High)**
1	Reduce TBB Groove Depth - Single Vee 2mm Depth of Prep.	Yes	Yes	Yes	No	No	No	Yes - Grind	No	M
2	Square Butt, 1mm TBB Groove, 100% Argon	Yes	Yes	No - Backside LoF	No	No	Yes - Laser ST?	Yes - Grind	No	H
3	Develop parameters to accommodate 2mm gap with current joint design - prove feasibility of Adaptive Fill Control	No	Unknown	Yes	Yes	Yes	Yes - High	No	No	H
4	Change weld prep - Single Bevel	Yes	Yes	Yes	No	No	No	Yes - Grind	No	M
5	Change weld prep, Reduce Amps & Travel Speed (possible nominal gap)	No	Yes	Yes	Yes	No	No	Yes - Shims prior to tack	No	M
6	Back Hand Torch Angle - constant	Yes	Yes	No - LoF, Porosity, Arc Cleaning	Yes	No	No	Yes	No	H
7	Offset Torch Lateral Position - constant	Yes	Yes	No - Contact angle, LoF	No	No	No	Yes	No	M
8	Larger Diameter Electrode	Yes	Yes	No - Contact angle, LoF	Unknown	No	No	No	No	M
9	Consumable TBB Groove Insert	Yes	Yes	No - LoF, Porosity	No	No	No	Yes	Yes	H

Appendix 10 (cont'd)

		Weld Quality Impact				Final Weld System Cost Impact				
Priority	Option	Exceed Top Reinforce Limit	Meet TYE	Meet Other Quality Requirements	Increase Distortion	Require Adaptive Fill Control	Add Equipment Costs	Add Processing Costs	Add Consumable Costs	Likely Gap Impact (Low-Medium-High)
10	Contact Tip Oscillation	No	Yes	Yes	No	No	Yes - Med	No	No	H
11	Torch Oscillation	Yes	Unknown	Yes	Yes	No	Yes - Low	Yes - Grind	No	H
12	Light Tack Weld Pass	No	Yes	No - Possible LoF, Porosity	No	No	No	Yes	No	H
	Square Butt, 1mm TBB Groove, He/Ar Mix	No	Yes	Yes	No	No	Yes - Laser ST?	No	Yes	H
	Reduce amps & travel speed (Assuming constant weld procedure)	No	Yes	Yes	No	No	No	No	No	L
	He/Ar Mix	No	Yes	Yes	No	No	No	No	Yes	M
	Offset Torch Work Angle - constant	Yes	Yes	No - Contact angle, LoF	No	No	No	Yes	No	M
	Offset Torch Work Angle - adaptive	Yes	Yes	No - Contact angle, LoF	No	Yes	Yes - High	Yes	No	M
	Offset Torch Lateral Position - adaptive	Yes	Yes	No - Contact angle, LoF	No	Yes	Yes - High	Yes	No	M
	Back Hand Torch Angle - adaptive	Yes	Yes	No - LoF, Porosity, Arc Cleaning	Yes	Yes	Yes - High	Yes	No	H
	Multiple Weld Passes	No	Yes	Yes	Yes	Yes	Yes - High	Yes	No	H
	Adaptive Fill Control - sense gap, change speed of travel, amp, volts	No	Unknown	Yes	Yes	Yes	Yes - High	No	No	H
	Twin Wire System									
	Weld Up Hill (~3 degrees)									

Appendix 11 –
Determination of Centriod, Final Parameters and Maximum Gap & Mismatch

Process Development – Status

- Centroid & Operating Parameter Envelop Defined
  - Ø 3/32" Weld Wire
  - Current = 375 ±10 amps
  - Travel Speed = 22.9 ± 2 ipm
  - Temporary Backing Bar Groove Depth = 1.25mm (0.050")
  - Fit-up Limits
    - Maximum limits with simultaneous Gap & Mismatch that achieved a stable process with a reasonable operating parameter window
    - Gap = 1.5mm (0.060")
    - Mismatch = 1.0mm (0.040")
    - Acceptable weld quality & stability with Gap = 2mm (0.080") & Mismatch = 2mm (0.080") when they occur independently
- Preliminary Qualification
  - Preliminary qualification tests were executed near the final Operating Point in mid-January
  - All tests will be re-done at the Centroid
  - Outstanding Issues are:
    - Root side re-entrant angle – will require grinding if minimum 90 degree limit is required
    - UTS Below 40ksi Limit (Min Value = 39.6ksi)
    - Face reinforcement – variable, but, typically above the 2.25mm (0.090") limit
      - Typical range 2.25-3.0mm (0.090" to 0.120") @ zero gap
- Tactile Seam Tracker
  - Tests with welding executed at Alcoa Technical Center
  - Seam Tracker purchased and installed on existing weld carriage
  - Weld lengths of 5 feet successfully completed with the seam tracker

Figure A11-1 – Process Development – Status

Process Development – January – February 2013

- Temporary Backing Bar – Groove Depth = 1.75mm (0.070")
  - Results promising on gap tolerance up to 2mm (0.080")
  - Parameter Operating Window shown to be narrow
  - Face Concavity became a limiting factor on wider gaps
    - Maintaining molten pool was difficult to control
    - Due to combined effects from the gap & deep groove in Temporary Backing Bar

Figure A11-2 – Process Development – January – February 2013

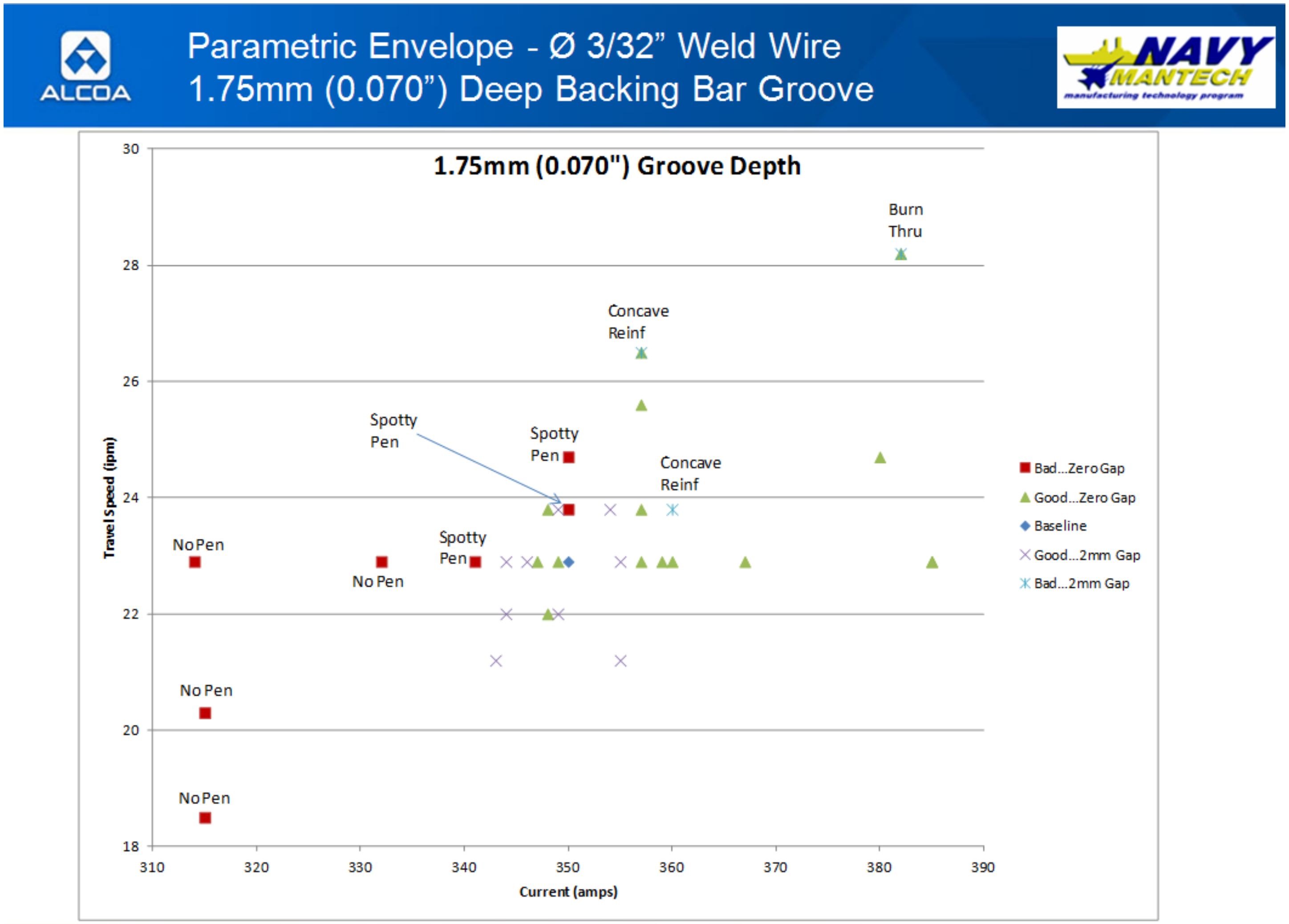


Figure A11-3 – Parametric Envelope – Ø 3/32" Weld Wire
1.75mm (0.070") Deep Backing Bar Groove

Process Development – Reduce Groove Depth

- Temporary Backing Bar – Groove Depth = 1.25mm (0.050")
  - Limits tendency to have concavity at large gaps
  - Significant improvement in tolerance to 2mm Gaps (0.080")
    - Increased range of feasible current & travel speed settings
  - Demonstrated acceptable quality at 2mm (0.080") Vertical Mismatch with 0mm Gap
  - Tests with combinations of Gap & Mismatch showed variable results
    - 2mm Gap & 2mm Offset – Not Feasible
    - 2mm Gap & 1.5mm Offset – Not Feasible
    - 1.5mm Gap & 1.5mm Offset – Inconsistent Quality
      - 16 Total Weld Trials
        - » 6 Bad
        - » 5 Marginal
        - » 5 Good
    - 1.5mm Gap (0.060") & 1.0mm (0.040") Offset
      - Consistent Quality
      - Acceptable Parametric Envelope

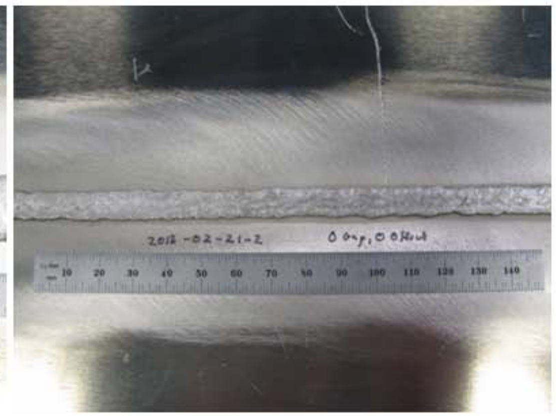
Figure A11-4 – Process Development – Reduce Groove Depth

ALCOA

0 Gap, 0 Offset

NAVY MANTECH manufacturing technology program

Face Reinforcement



Root Reinforcement

2013-02-21-2
372 Amps 22.9 IPM
Good Weld Quality (Video)

1.25mm (0.050") Deep Backing Bar Groove

Figure A11-5 – Top (Face) & Root Weld Reinforcement – 0 Gap, 0 Offset

1.5mm (0.060") Gap, 1.0mm (0.040") Offset

Face Reinforcement

Root Reinforcement

2013-02-19-1
364 Amps 20.3 IPM
Good Weld Quality

1.25mm (0.050") Deep Backing Bar Groove

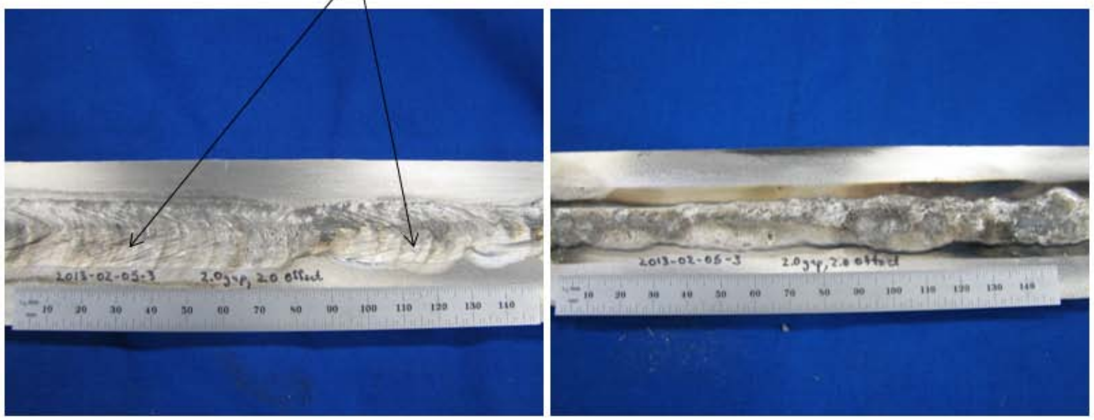
Figure A11-6 – Top (Face) & Root Weld Reinforcement – 1.5mm (0.060") Gap, 1.0mm (0.040") Offset

Appendix 11 (cont'd)

2mm (0.080") Gap, 2mm (0.080") Offset

Concavity

Root Reinforcement –
Significantly Wider



Face Reinforcement

Root Reinforcement

2013-02-05-3
385 Amps 23.8 IPM
Poor Weld Quality, Concavity

1.25mm (0.050") Deep Backing Bar Groove

Figure A11-7 – Top (Face) & Root Weld Reinforcement – 2mm (0.080") Gap, 2mm (0.080") Offset

2mm (0.080") Gap, 1.5mm (0.060") Offset

Burn Thru

Face Reinforcement

Root Reinforcement

2013-02-06-2
378 Amps 22.9 IPM
Poor Weld Quality, Burn Thru

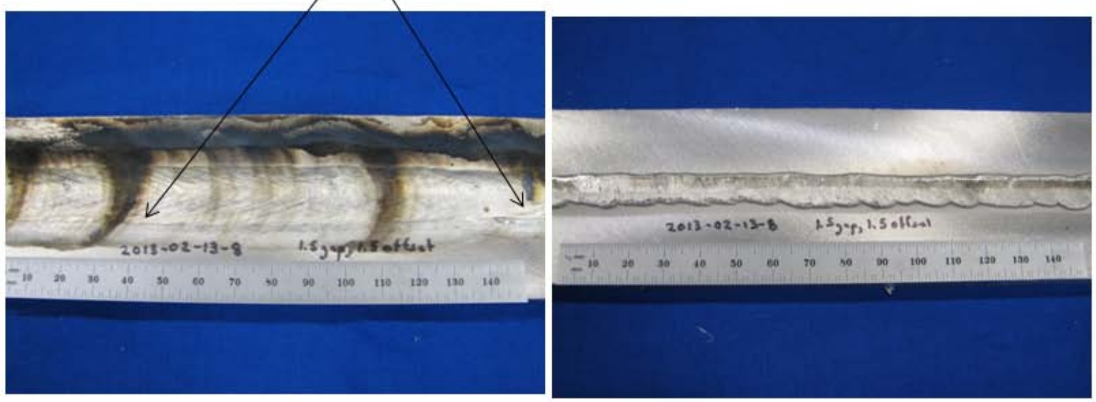
1.25mm (0.050") Deep Backing Bar Groove

Figure A11-8 – Top (Face) & Root Weld Reinforcement – 2mm (0.080") Gap, 1.5mm (0.060") Offset

Appendix 11 (cont'd)

1.5mm (0.060") Gap, 1.5mm (0.060") Offset

Concavity



Face Reinforcement

Root Reinforcement

2013-02-13-8
363 Amps 22.9 IPM
Poor Weld Quality

1.25mm (0.050") Deep Backing Bar Groove

Figure A11-9 – Top (Face) & Root Weld Reinforcement – 1.5mm (0.060") Gap, 1.5mm (0.060") Offset

1.5mm (0.060") Gap, 1.5mm (0.060") Offset

Slight
Concavity

Face Reinforcement

Root Reinforcement

2013-02-13-7
385 Amps 23.8 IPM
Marginal Weld Quality

1.25mm (0.050") Deep Backing Bar Groove

Figure A11-10 – Top (Face) & Root Weld Reinforcement – 1.5mm (0.060") Gap, 1.5mm (0.060") Offset

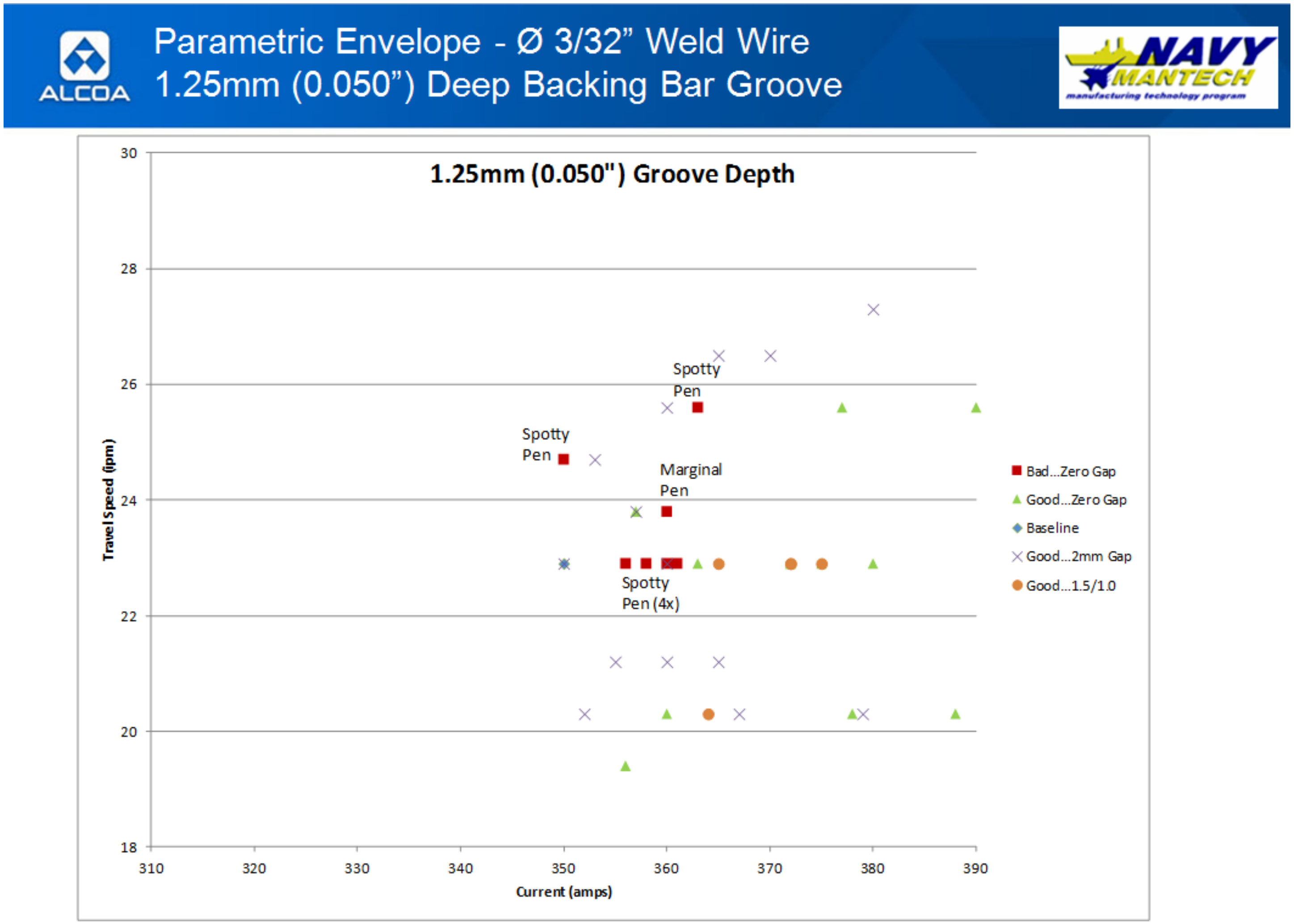


Figure A11-11 – Parametric Envelope – Ø 3/32" Weld Wire
1.25mm (0.050") Deep Backing Bar Groove

Appendix 12 –

Flat Down Hand Welding Weld Procedure Specification (WPS) and Weld Procedure Qualification Record (WPQR)

FDH Weld Procedure Specification Summary

Backing:
Type – Temporary – Grooved 1.3mm (0.05”) x 25.4mm (1.0”)
Material - Anodized Aluminum

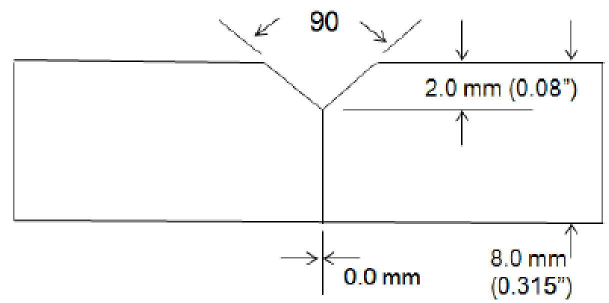
Position:
Flat (1G)

Electrode / Filler:
Alloy – ER5183
Diameter – 0.093 in. (2.4mm)

Shielding Gas:
Argon
Flow Rate: 50 SCFH

Preheat Temperature:
None

Torch Angle:
Work Angle: 0.0
Lead Angle: 15 degrees



GMA Parameters:

Current Type: Constant Current (CC)
Current-Polarity: DC-EP

Average Amperage: 369 Amp
Average Voltage: 31.0 Volt

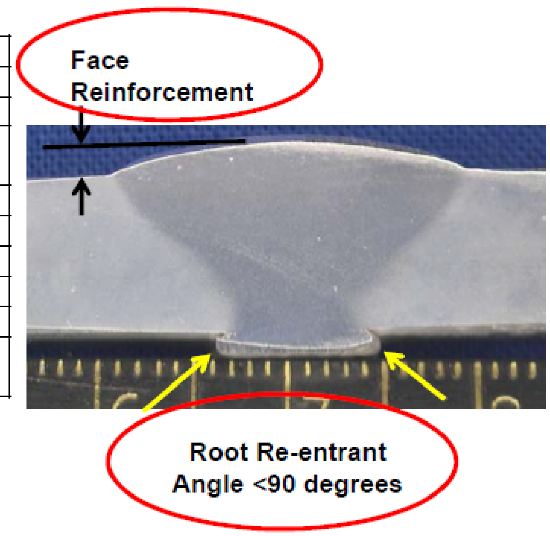
Travel Speed: 22.9 IPM

Number of Weld Passes: 1

Figure A12-1 – FDH Weld Procedure Specification Summary

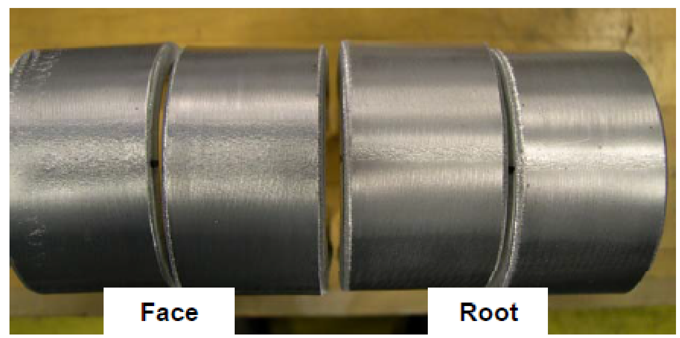
FDH Weld Procedure Qualification Record Summary

Test	Note/Condition	Result
Visual		No cracks or porosity
		Face coutour passes, but, borderline
		Root Rentrant Angle must be ground to >90 degrees
Radiographic	As Welded	No indications
Penetrant	As Welded	No indications - Face & Root
Radiographic	Face & Root Removed	No indications
Penetrant	Face & Root Removed	No indications - Face & Root
Bends - Face & Root	6.66t (13% Elongation)	Pass
Tensile, Yield & Elongation		Fail - Not all specimens meet 40ksi Minimum UTS



Tensile Yield & Elongation

Specimen*	Thickness	Width	YS (ksi)	UTS (ksi)	Elongation
895354-1	0.3147	1.499	20.1	39.9	16.0
895354-2	0.3091	1.5	20.2	39.9	16.0
895354-3	0.3137	1.5	20.3	40.2	16.0
895354-4	0.3207	1.5	20	40	16.0
*TYE 1 and 3 - Start, TYE 4 and 2 - End					



Bend Tests

Proj # S2404 – High-Productivity Aluminum Manufacturing

Figure A12-2 – FDH Weld Procedure Qualification Record Summary

Appendix 13

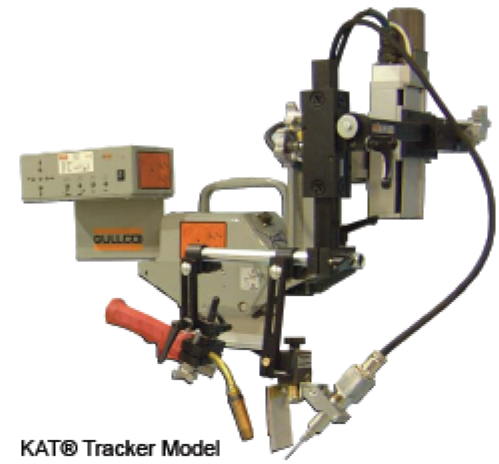
Gullco WSG-1200 Seam Tracking System

The quality and efficiency achieved with today's automated welding systems can be impaired by material warpage, misalignment, irregular edge fit-up, different material thickness and other conditions that cause variations in the weld seam. Gullco KAT® Trackers restore optimum performance when these conditions are encountered. They continually sense the slightest variation across the weld seam and automatically correct the position of the weld torch.

The trackers are designed for incorporation and use with the Gullco KAT® travel carriage system but can readily be used with other travelling and rotating devices employed in automated welding operations.

The systems are effectively employed to cut costs and increase productivity in a wide range of applications such as tank, pressure vessel, pipe and structural component fabrication and deep groove welding operations.

Gullco KAT® Trackers are available in standard or heavy duty models to meet virtually all requirements. A brief description of each is provided below.



KAT® Tracker Model WSG-1200 Electronic Seam Tracker

KAT® Trackers are precise, dependable and highly versatile. They can be used with a wide range of Gullco accessories/ systems such as oscillators, bridge units, multiple torch assemblies etc. Contact Gullco with your requirement.

GULLCO KAT® TRACKERS
These Trackers provide precise vertical and horizontal tracking plus...

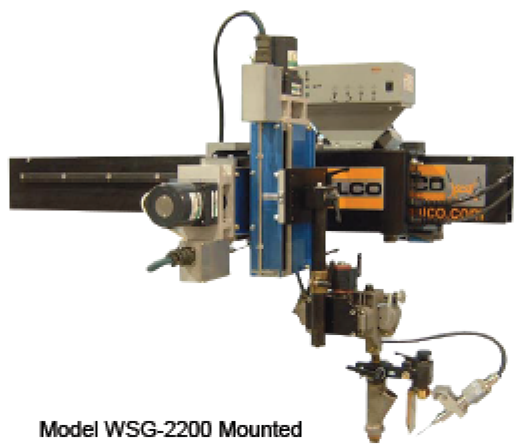
ELECTRONIC "END OF PLATE DETECTION"
- puts the tracking system on "hold"... Preventing the torch from driving into the plate and allowing welding to continue to the plate edge.

ELECTRONIC "TACK DETECTION"
- interrupts the automatic tracking action when a tack-weld is encountered preventing the torch from rising prematurely...and returns the system to normal action when it reaches the end of the tack weld.

MODEL WSG-1200:
This model has up to 55 lb. (25kg) vertical load capacity at 4" (100mm) extension from the face plate. The standard stroke is 4" x 4" (100x100mm).

MODEL WSG-2200:
The heavy duty version of model WSG-2200 with a vertical load capacity up to 100 lbs. (45 kg) at 6" (150mm) extension from the face plate. The standard stroke is 6"x6" (150x150mm).

Note: The above data applies to standard slide assemblies. Other slide lengths, speed and higher capacities are available.



Model WSG-2200 Mounted on a side beam carriage equipped with a submerged arc head

Reference – www.gullco.com

SPECIFICATIONS

GULLCO MODEL WSG-1200 KAT® TRACKER SYSTEM SYSTEM COMPONENTS
Main Control Box, Pendant Remote Control Box, Probe, Probe Micro Cross-Slide, Motorized Cross-Slide Assembly, Probe-To-Torch Mounting Bracket, Control Cables from Probe and Cross-Slide to Main Control Box, Torch Holder with vertical/ horizontal adjustment, Brackets for mounting Cross-Slide and Main Control Box on KAT® Travel Carriage.

MAIN CONTROL BOX
Incorporates main power switch, On/Off pilot light, signal lights indicating sensing function and fuse. Electronic circuit components incorporated in modular system with circuit boards for easy maintenance.
Size: (H) 5-1/2" (W) 2" (D) 1-1/2" (140 x 50 x 38mm.)
Weight: 2 lbs. (900 grams)

PENDANT REMOTE CONTROL BOX
Incorporates manual/automatic changeover switch and inching switch -vertical up/down and horizontal left/right.
Size: (H) 5-1/2" (W) 2" (D) 1-1/2" (140 x 50 x 38mm.)
Weight: 2 lbs. (900 grams)

PROBE
Supplied complete with replaceable 1/8" dia. Probe tip. The assembly incorporates a Shock Protector that protects the system's electronics by breaking when heavy shock is encountered.

PROBE MICRO CROSS SLIDE
Provides precise manual pre-positioning of probe relative to torch prior to automatic operations.
Stroke plus or minus 3/4" (20mm).
Weight: 1-3/4 lbs. (900 grams)

MOTORIZED CROSS-SLIDE ASSEMBLY

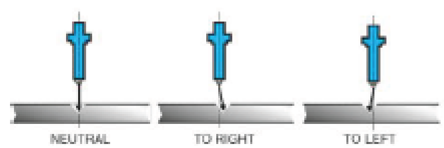
Model	WSG-1200	WSG-2200
Vertical Load Capacity:	up to 55 lbs. (25kg)	up to 100 lbs
Standard Stroke Length:	4" (100mm)	6" (150mm)
Standard Stroke Speed:	10.16 in/min	9.8 in/min
Height	14" (355mm)	18 1/2" (472mm)
Width	14" (355mm)	18 1/2" (472mm)
Depth	4 3/4" (120mm)	6 1/2" (170mm)
Weight	22 lbs. (10kg)	50.6 lbs. (23kg)

Power Requirements: 110/115 Volt AC - Single phase 50/60 Hz
Longer slides, other speeds and higher capacity units available on request.

...incorporating sensing modes that cover virtual all tracking requirements

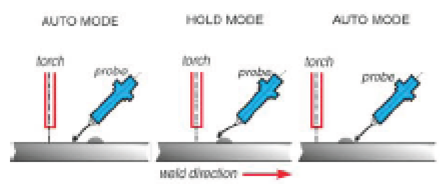
GULLCO KAT® TRACKERS MODEL WSG-1200 & 2200 SINGLE DIRECTION SENSING

TWO DIRECTIONAL RIGHT/LEFT SENSING



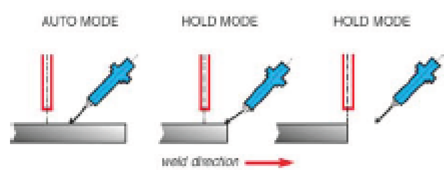
plus...

WELD TACK DETECTION



plus...

END OF PLATE DETECTION



Reference – www.gullco.com

Gullco Mechanical Seam Trackers and Height Sensors are designed for use with the Gullco KAT® Travel Carriage to accurately maintain the required, pre-set distance between the gun or torch and the workpiece in automated welding and cutting operations.

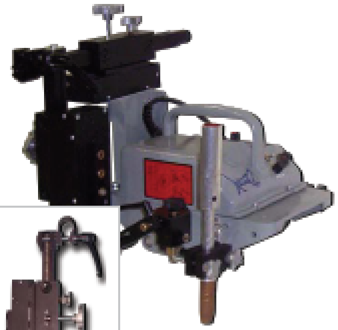
Three models are available to effectively meet various application needs. All are constant velocity, spring-type sensors utilizing hardened and ground slide bars with recirculator ball bushings to provide 1-3/4" (44mm) of torch float.*

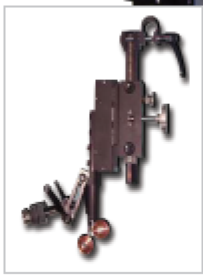
Model GK-190-600 Height Sensor has an adjustable swivel copper guide wheel to contact the work surface.

Model GK-190-602 Height Sensor has a stainless steel ball transfer that is particularly useful to maintain contact on curved surfaces or vertical applications.

Model GK-190-603 Seam Tracker is specifically designed for fillet welding applications.

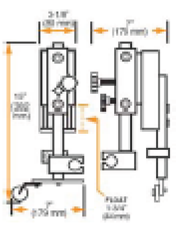
**Other float distances available on request.*





MODEL GK-190-600
Mechanical Height Sensor with constant velocity spring, hardened ground rods and circulator ball bushings to provide 1-3/4" (44mm) of torch float.

Supplied complete with adjustable, swivel copper guide wheel, 1-1/8" (29mm) sq. rack box, 12" (304mm) rack arm and swivel mounting clamp for attachment to KAT® Travel Carriage arm.



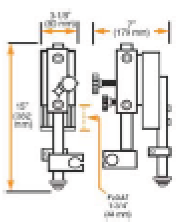
MODEL GK-190-602
Mechanical Height Sensor with constant velocity spring, hardened ground rods and circulator ball bushings to provide 1-3/4" (44mm) of torch float.

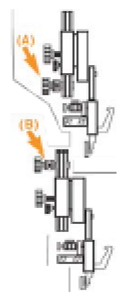
Supplied complete with hardened stainless steel ball assembly, 1-1/8" (29mm) sq. rack box, 12" (304mm) rack arm and swivel mounting clamp for attachment to KAT® Travel Carriage arm.

MODEL GK-190-603
Mechanical Seam Tracker with constant velocity spring, hardened ground rods and recirculator ball bushings to provide 1-3/4" (44mm) of 45° torch float and 1-1/4" (31.75mm) of weld seam misalignment in both the horizontal and vertical plane. The assembly includes a Micro Cross-slide with gun holder to provide 3/4" (19mm) of XY adjustment. Supplied as standard with single copper guide wheel, 1-1/8" (29mm) sq. rack box, 12" (304mm) rack arm and 1-1/8" (29mm) swivel mounting clamp for attachment to KAT® Carriage rack arm.

(A) When the weld seam is below the Kat carriage level, the sensor rack arm clamp is located below the sensor rack box.

(B) When the weld seam is above carriage level the sensor rack arm clamp is positioned above the sensor rack box. Additional height adjustment may be required. We recommend the use of our Rack Box Riser Assembly (below) to increase the carriage rack arm height by 2", 4" or 6"

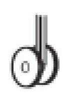




SPECIAL SENSOR GUIDE WHEEL ASSEMBLIES
For Fillet Welding applications involving tack welds

Model GK-190-604
Dual in-line guide wheels react independently when tack welds encountered on thin edge material, one always in contact with the weld seam.

Model GK-190-606
Dual, side-by-side guide Wheels straddle tack weld Line in general range of Fillet Weld applications.



SPECIFICATIONS ARE SUBJECT TO CHANGE WITHOUT NOTICE

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WWW.GULLCO.COM

ST-11-01

Reference – www.gullco.com

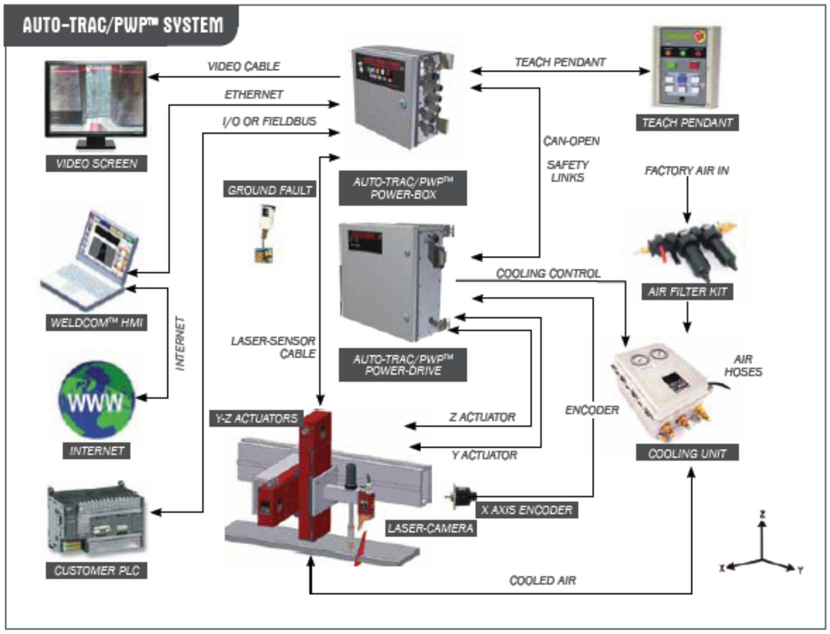
Appendix 14
Servo-Robot LaserWeld SeamTracking

Reference – www.servorobot.com

Appendix 14 (cont'd)

AUTO-TRAC/PWP™

COMPLETE SOLUTION FOR JOINT TRACKING AND ADAPTIVE PROCESS CONTROL DESIGNED FOR SPECIAL WELDING MACHINES



FEATURES AND BENEFITS

- Fully integrated standard system includes laser camera, control unit, actuators, teach pendant and software ready to use.
- Immune to the Arc welding processes (spatter, heat, etc.).
- Not affected by ambient lighting conditions.
- Can track on any weldable material including aluminum.
- Pressurized air flow protects disposable lens against dust and fume.
- High speed digital laser-sensor allows for fast and reliable joint recognition.
- Extensive template library includes all standard and non-standard weld joints.
- Automatic joint recognition.
- Teach and Playback capability.
- Adaptive process control firmware interfaced directly with the welding equipment.
- High speed rugged actuators for precise torch positioning.

Reference – www.servorobot.com

Appendix 14 (cont'd)

EASY OPERATION

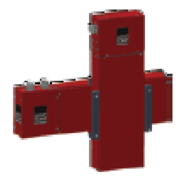
Operation is made by the operator or by the PLC through an I/O interface. The easy to use teach pendant allows for quick setup and selection of the correct program as well as a simple calibration. In addition, the teach pendant always provides the system status to the operator. The axes positions can be taught like a robot.

AUTO-TRAC/PWP™ CONTROLLERS

The AUTO-TRAC/PWP™ main controller is the POWER-BOX™. It is a powerful processing unit that manages the system sequence, the laser-camera profiles processing, the trajectory computation and the process adaptive control (optional). A CAN-Open interface links it to the POWER-DRIVE™ controller which is driving the axes. Up to 3 axes can be driven and a fourth one can be interfaced to read the encoder of a positioner or gantry.

The system offers various possibilities to be interfaced with PLC's and welding power sources through Digital I/O, analog signals or field bus.

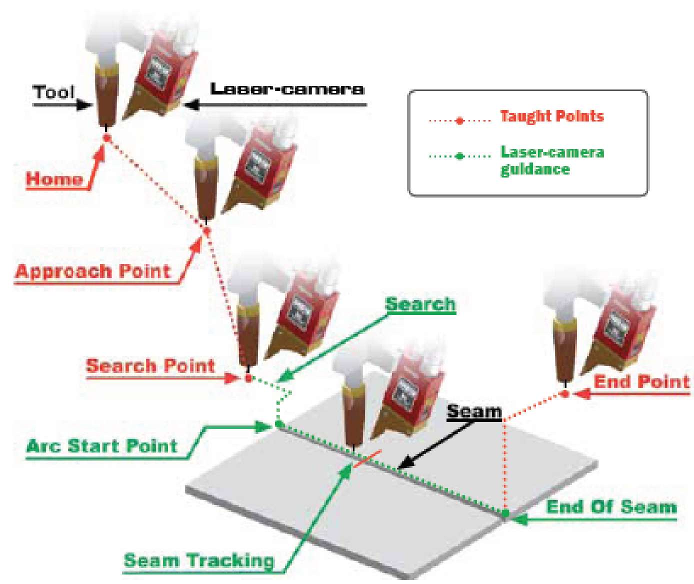
Teach pendant



High-speed actuators

AUTO-TRAC/PWP™ POWER-BOX (300x300x150mm, 4 kg)

AUTO-TRAC/PWP™ POWER-DRIVE (600x600x200mm, 23kg)



TYPICAL APPLICATIONS

- Pressure Vessels
- Bridges Structures
- Shipbuilding
- Wind Tower Turbines
- Water Heater Tanks
- Railway Cars
- Pipe (Spiral and UO pipe)

EXCLUSIVE FUNCTIONS

AUTO-TRAC/PWP is designed to operate on any joint preparation ranging from sheet metal to heavy plate complex grooves.

AUTO-TRAC/PWP can be taught like a robot.

In addition, the encoders allow one to generate the proper trajectory while tracking, taking into account the travel speed, the position of the camera related to the torch and the current positions of the torch. The end result is a sound weld that meets the most stringent quality requirements.

Path memorization and playback function is very helpful in the multipass applications.

AUTO-TRAC/PWP™

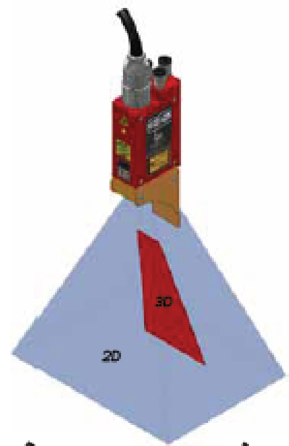
Reference – www.servorobot.com

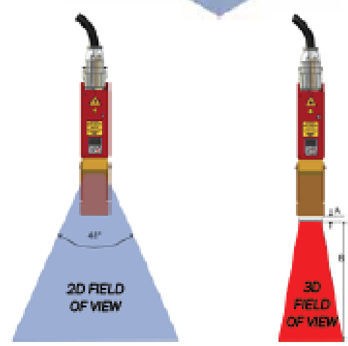
Appendix 14 (cont'd)

POWER-CAM™ LASER-CAMERA

This compact high-speed digital laser-camera features high-resolution, programmable field of view combined with a high frame rate. This camera includes an integrated 2D color video camera allowing joint monitoring as well as remote operation.

	POWER-CAM
Laser class	IIIb
A: Stand-off distance (mm)	5
B: Field of view depth (mm)	140
Field of view width	
C: Close plane (mm)	27
D: Far plane (mm)	76
Average depth resolution (mm)	0.10
Average lateral resolution (mm)	0.05
Dimensions (mm)	33W x 58D x 94H
Weight (g)	500
Casing machined in a light alloy block	✔
Cooling channel machined in the frame	✔
Exchangeable front lens	✔
Automatic detection of exchangeable front lens presence	✔
Reference mechanical dovetail for easy and accurate laser-camera installation	✔
2D color video camera integrated	✔
High quality industrial connector (military type)	✔
Flexible robotic cables provided	✔





Reference – www.servorobot.com

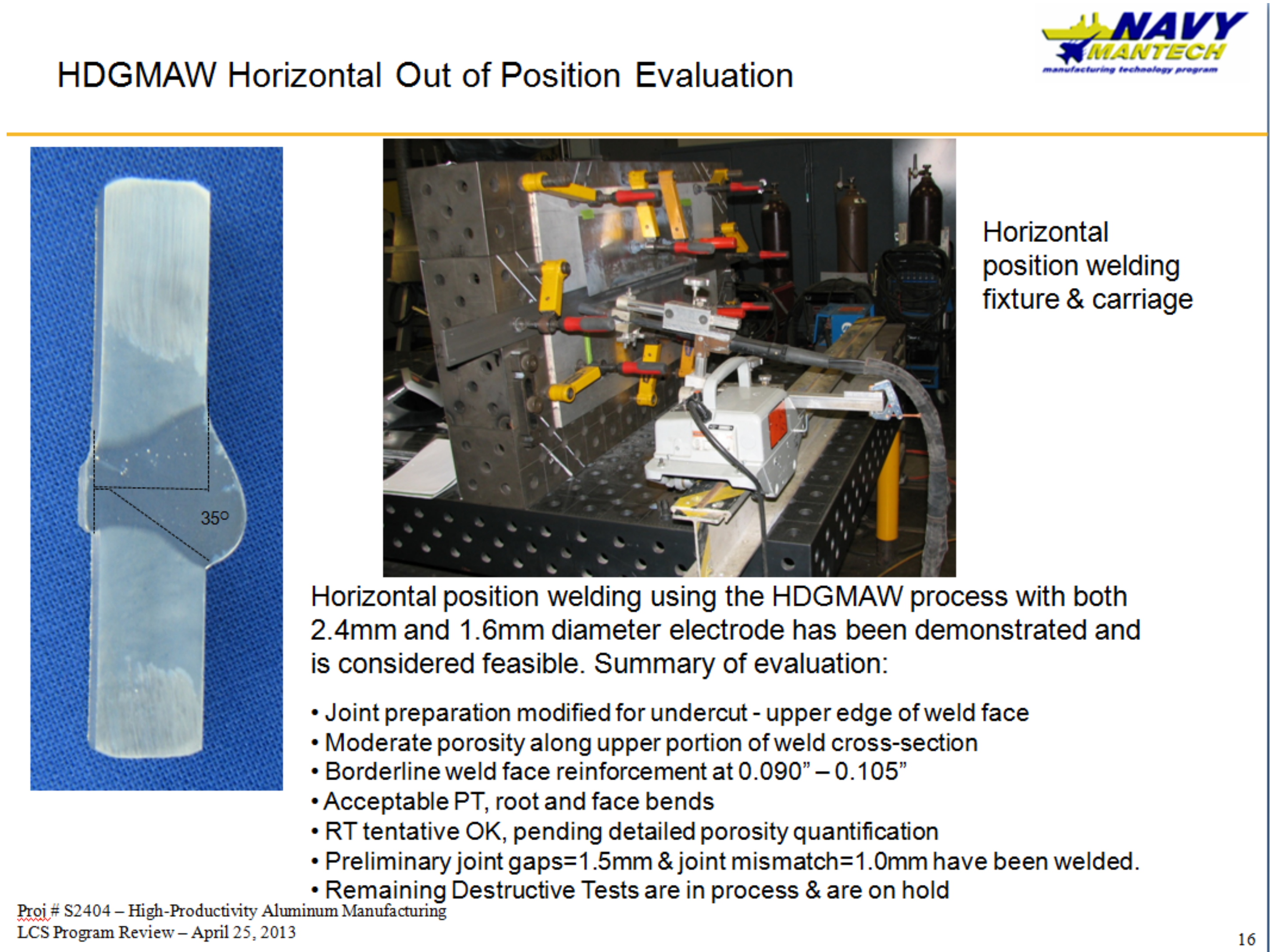
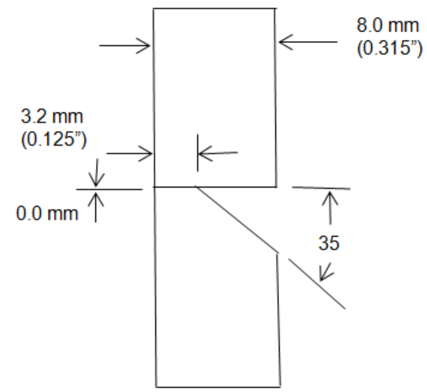


Figure A15-1 – HDG MAW Horizontal Out-of-Position Evaluation

OOP Weld Procedure Summary

Backing:
Type – Temporary – Grooved 1.3mm (0.05”) x 25.4mm (1.0”)
Material - Anodized Aluminum

Position:
Horizontal (2G)



Electrode / Filler:
Alloy – ER5183
Diameter – 0.093 in. (2.4mm)

Shielding Gas:
Argon
Flow Rate: 50 SCFH

Preheat Temperature:
None

Torch Angle:
Work Angle: 10.0
Lead Angle: 15 degrees

GMA Parameters:

Power Supply: ESAB 652 CVCC
Wire Feeder: MIG 35
Torch/Gun: L-TEC ST21 - Push
Current Type: Constant Current (CC)
Current-Polarity: DC-EP

Average Amperage: 368 Amp
Average Voltage: 32.0Volt

Travel Speed: 33.5 IPM

Number of Weld Passes: 1

1

Figure A15-2 –Out-of-Position Weld Procedure Summary

OOP Weld Procedure Summary

Backing:
Type – Temporary – Grooved 1.3mm (0.05”) x 25.4mm (1.0”)
Material - Anodized Aluminum

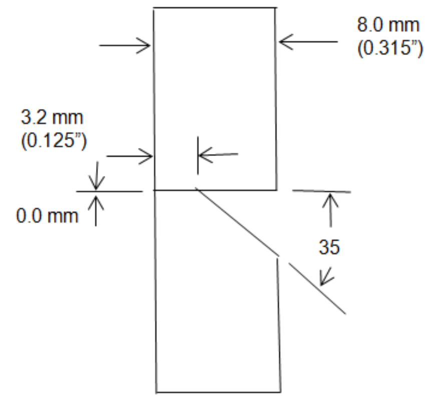
Position:
Horizontal (2G)

Electrode / Filler:
Alloy – ER5183
Diameter – 0.063 in. (1.5mm)

Shielding Gas:
Argon
Flow Rate: 50 SCFH

Preheat Temperature:
None

Torch Angle:
Work Angle: 10.0
Lead Angle: 15 degrees



GMA Parameters:

Power Supply: Lincoln Power Wave 455M
Wire Feeder: Lincoln Power Feed 25M
Torch/Gun: MK Products Python – Push-Pull
Current Type: Power Mode (Program 40)
Current-Polarity: DC-EP

Average Amperage: 334 Amp
Average Voltage: 28.8Volt

Travel Speed: 23.8 IPM

Number of Weld Passes: 1

1

Figure A15-3 –Out-of-Position Weld Procedure Summary

Appendix 16-1 - Testing of HDGMAW for Acceptance as a New Weld Process – Porosity

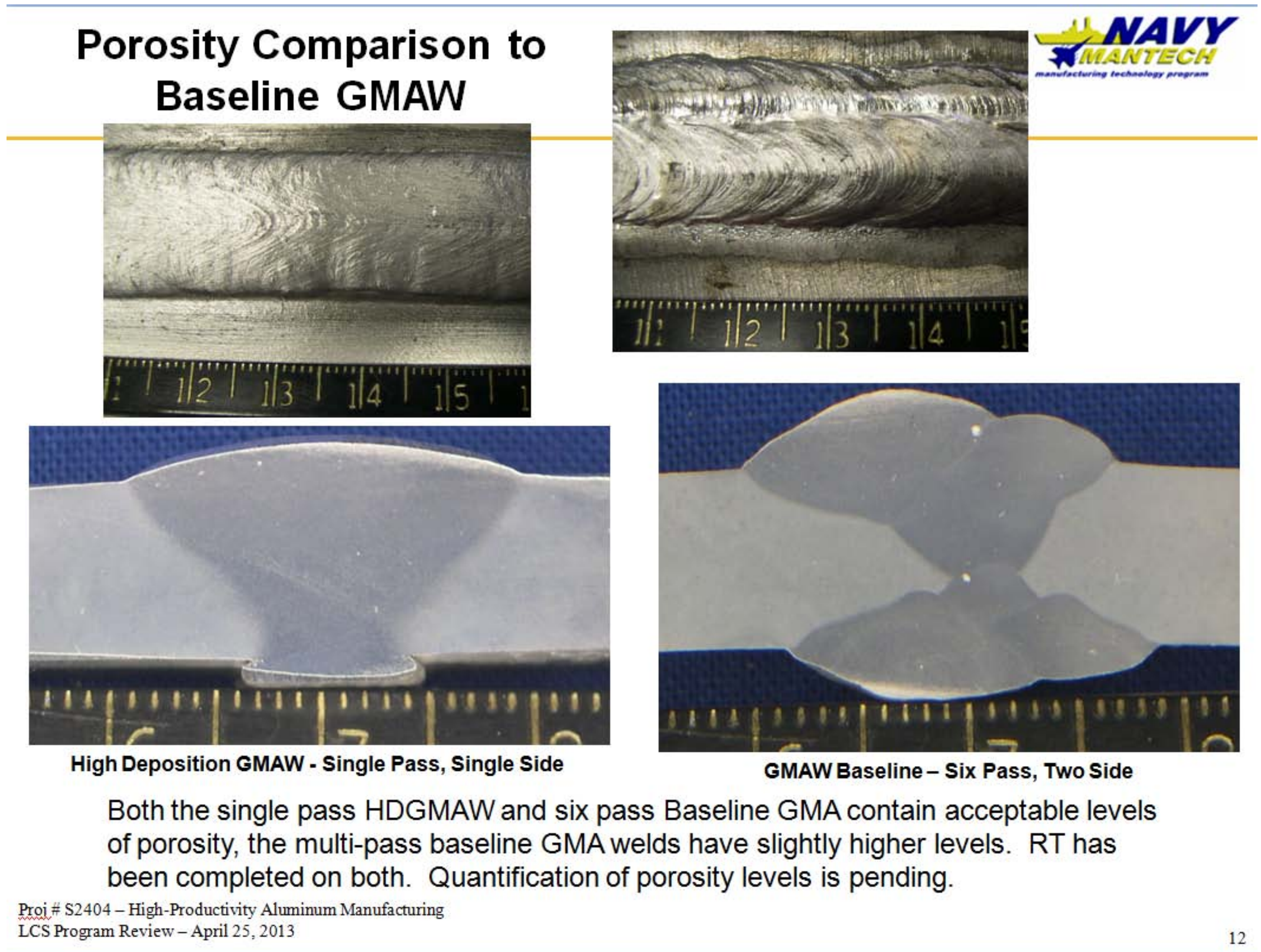
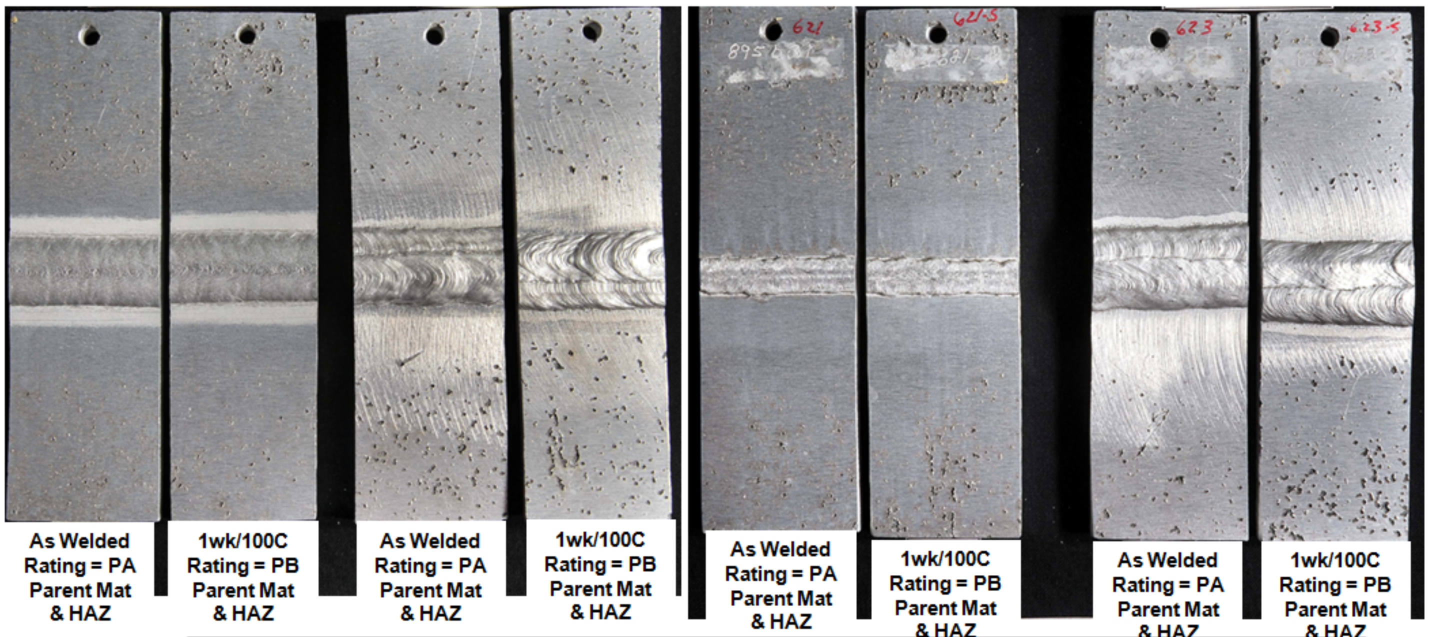


Figure A16-1 – Porosity Comparison to Baseline GMAW

Corrosion Comparison to Baseline GMAW XM-308 24hr ASSET (ASTM G66)

Face Side of Weldment — HDGMAW | Baseline

Root Side of Weldment — HDGMAW | Baseline



- No evidence of Exfoliation Corrosion
- Some Pitting Corrosion as Expected
- All specimens Pass with rating of PA or PB
- No evidence of Preferential Corrosion in the HAZ
- Some enhanced Pitting Corrosion in Baseline GMAW in the Parent Material

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Figure A16-2 – Corrosion Comparison to Baseline GMAW XM-308 24hr ASSET (ASTM G66)

Appendix 16-3 - Testing of HDGMAW for Acceptance as a New Weld Process – Distortion

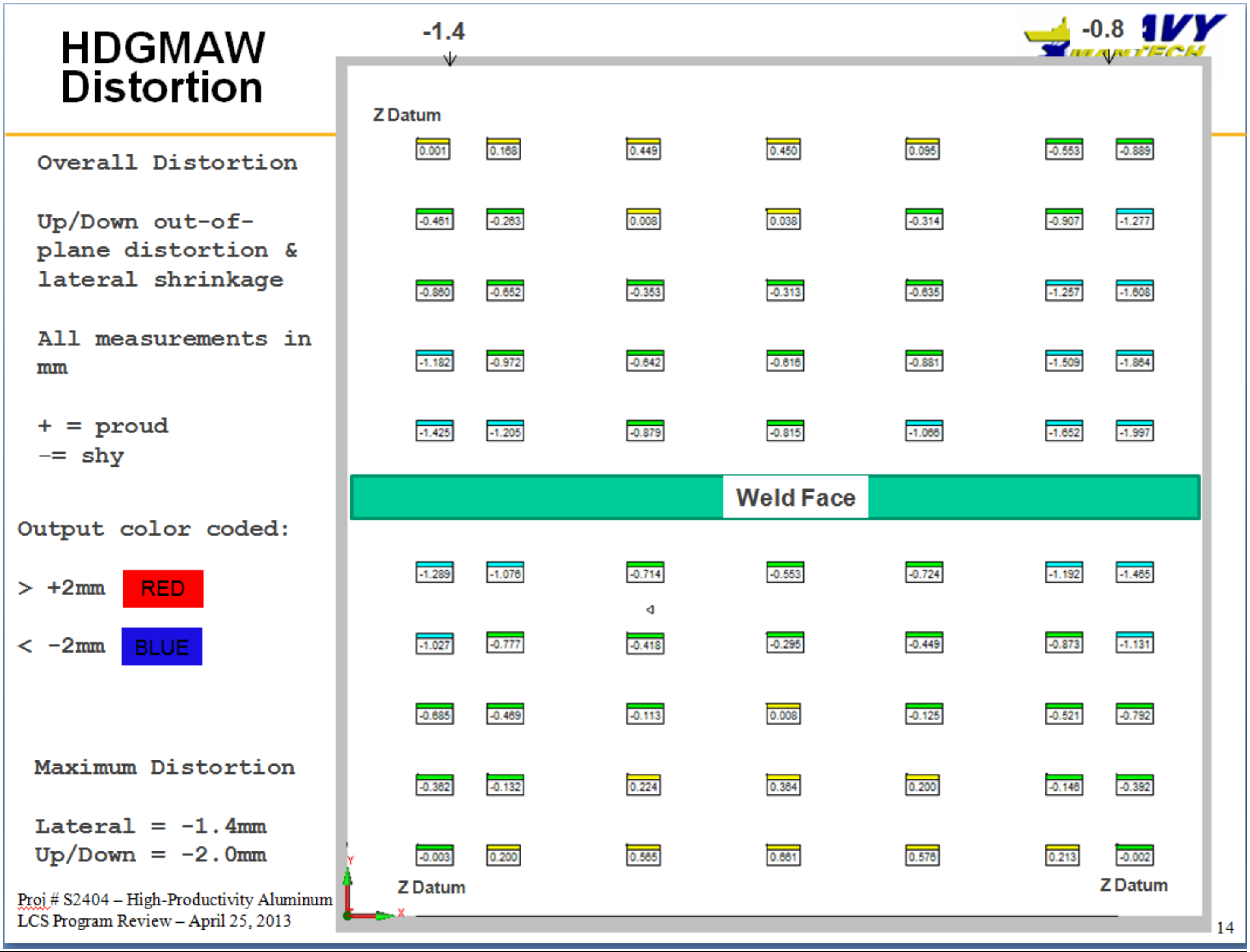


Figure A16-3-1 – HDGMAW Distortion

Appendix 16-3 (cont'd)

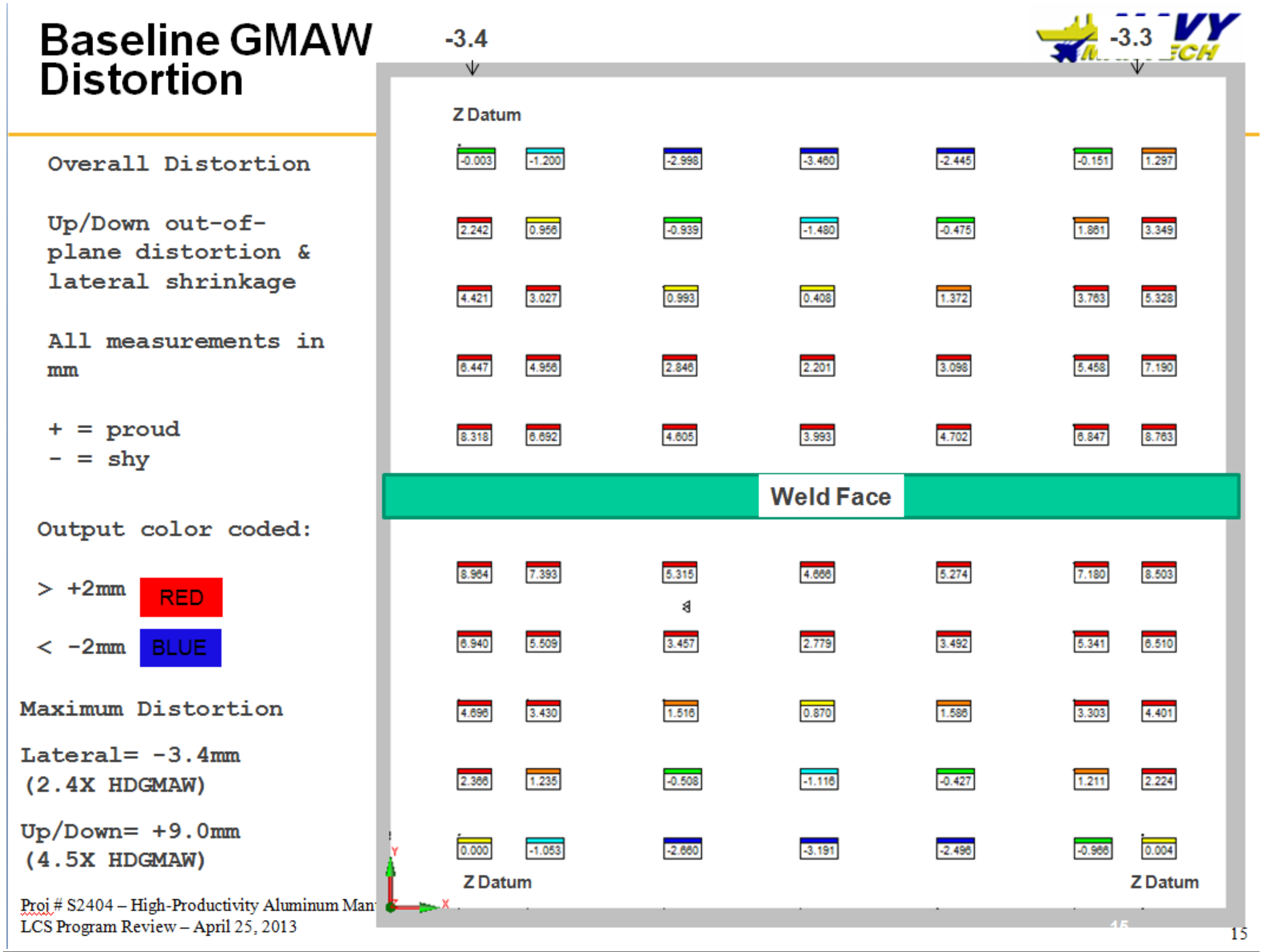


Figure A16-3-2 – Baseline HDGMAW Distortion

Cost Modeling of GMAW and HDGMAW process for 0.157" (4mm) Thick Butt Joints Alloy 5086-H116 in a complete ship structure

Kirit Shah

August 23, 2013

Objective

- Compare assembly cost of GMAW and HDGMAW process utilizing SEER-MFG cost modeling.

Overview of SEER-MFG Cost Modeling Tool

- Commercial estimation package SEER-MFG (www.galorath.com)
- Employed by several major Defense Original Equipment Manufacturers
- Labor, material, and tooling estimates for major steps are developed based upon industry standards
  - Plasma cutting, routing, material transfer, fixturing, multi-pass GMAW welding, inspection, rework operations
  - Labor costs are based upon time standards (calculated by SEER-MFG) * labor rates (assigned by user)

LIGHTER, FASTER, STRONGER 1

Figure A17-1 – Overview of SEER-MFG Cost Modeling Tool

Appendix 17 – Cont'd

Cost Model Assumptions

- **Labor Rates**
  - $75/hr (assumed Fab Shop average rate – fully burdened) for both GMAW and HDGMAW process
- **Consumable Costs**
  - $4/lb 5183 weld wire (utilization included)
    - Deposition Rates: GMAW ~ 6lbs/hr, ~ 8 lbs/hr for HDGMAW
  - $0.06 /cuft Argon
    - 50 CFH flow rate, 66 CFH flow arte for HDGMAW
- **Build Quantity – 100 assemblies**
- **4 mm Weld Thickness**
- **As details for Fit-up is most unknown in the analysis, The labor required for Fit-up is assumed to be 1.5X higher for HDGMAW process compare to GMAW based on preliminary data. Sensitivity of the results to factor is included in the analysis.**
- **Non recurring cost is not considered in the analysis.**

LIGHTER, FASTER, STRONGER 2

Figure A17-2 – Cost Model Assumptions

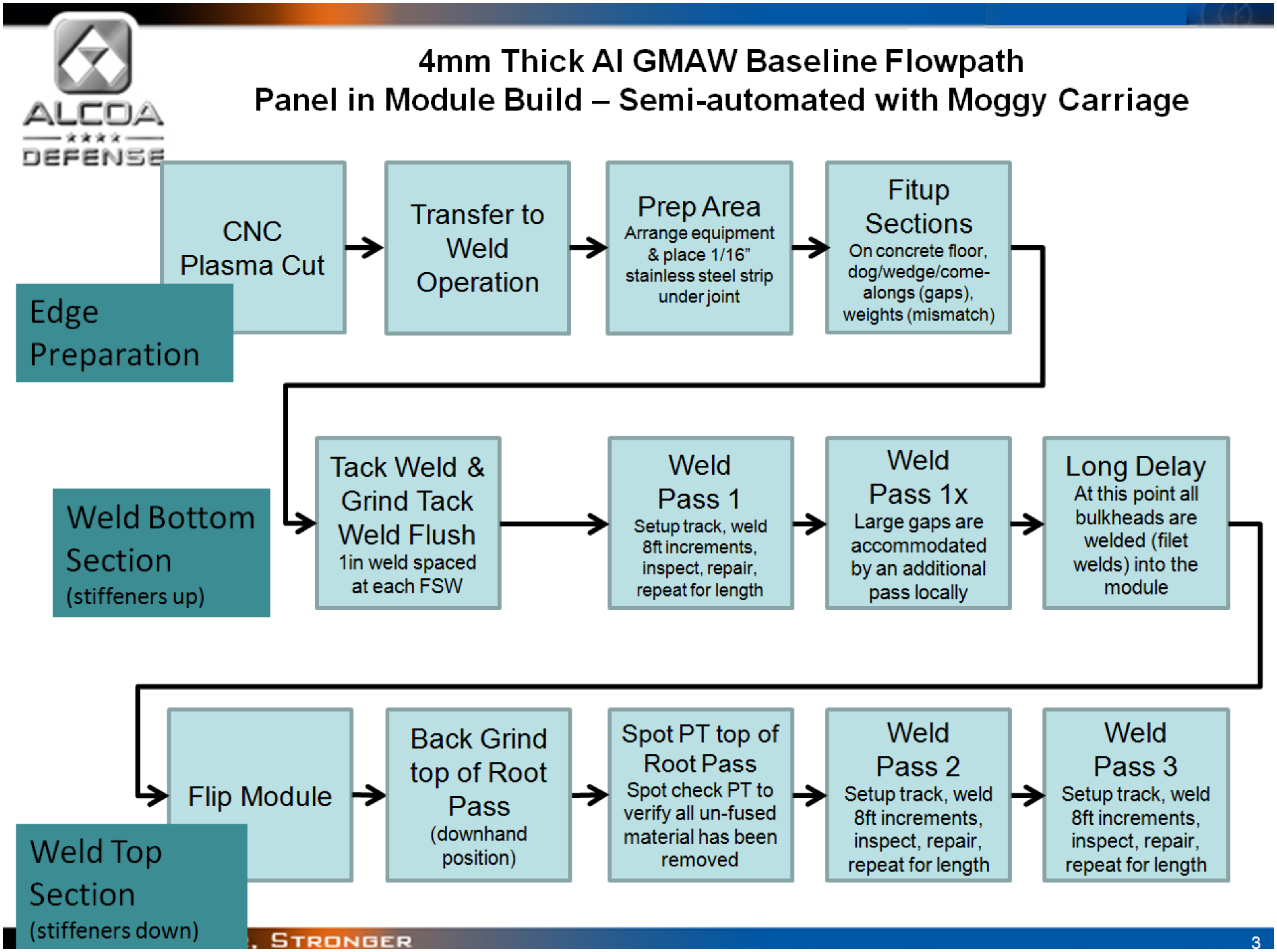


Figure A17-3 – 4mm Thick Al GMAW Baseline Flowpath Panel/Floor in Module Build – Semi-automated with Moggy Carriage

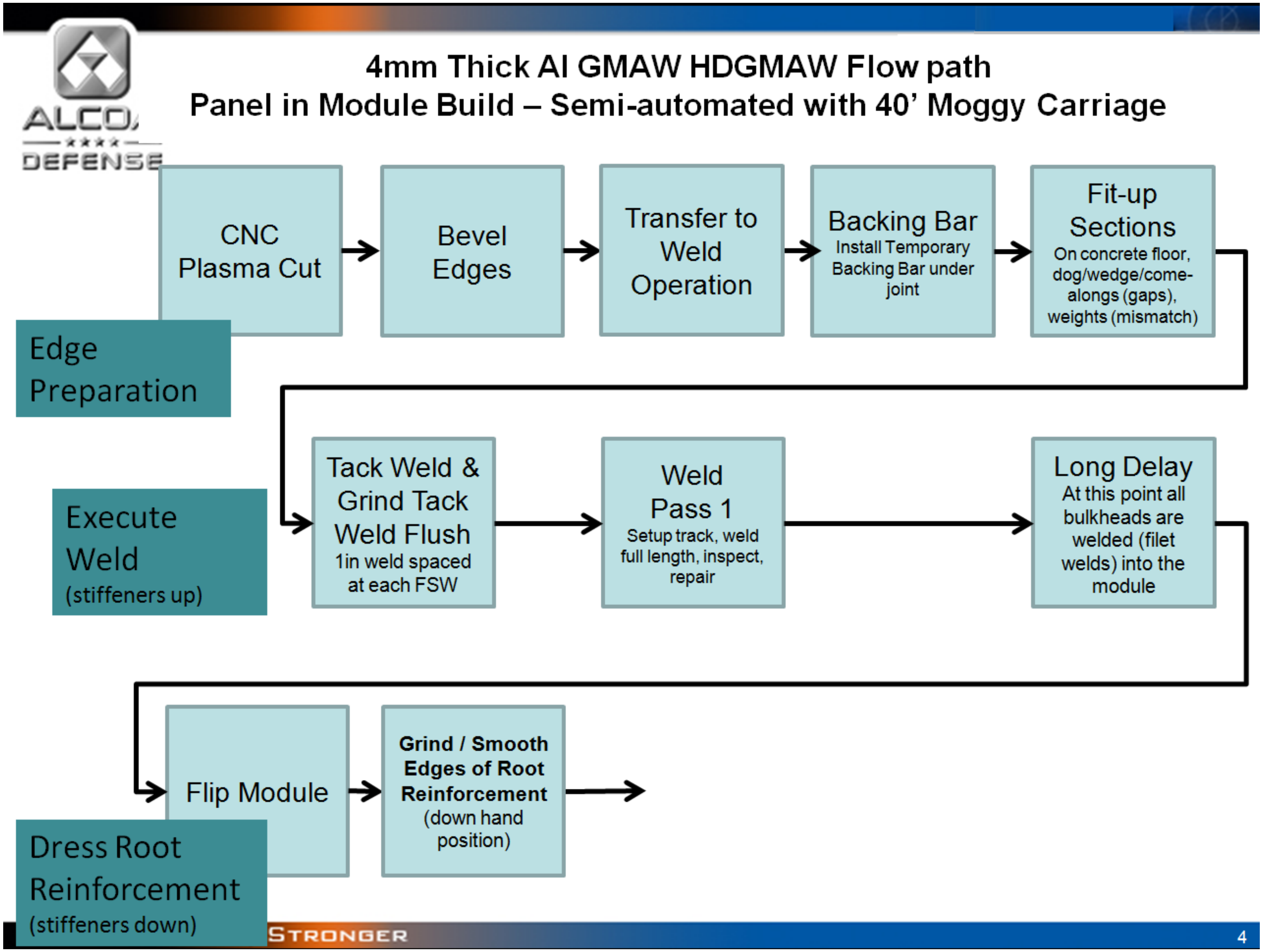


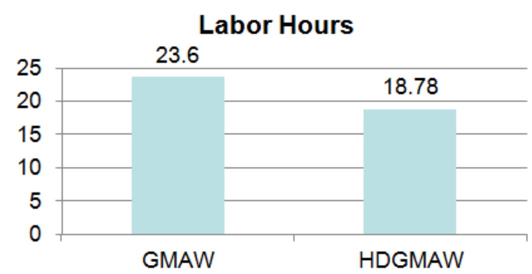
Figure A17-4 – 4mm Thick Al GMAW HDGMAW Flowpath
Panel in Module Build – Semi-automated with 40' Moggy Carriage

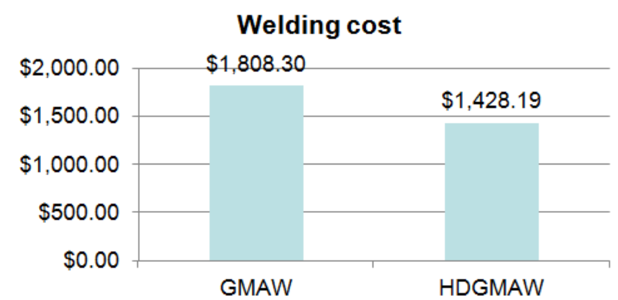
Detail Cost Analysis Results for Welding Panel to Panel in a Module - Semi-Automated with Moggy Carriage

Weld No 1, FDH weld , Total Weld Length = 49.5 ft.

GMAW	Labor Hrs/Unit	Cost/Unit
Baseline flow lath		
CNC Plasma Cut Section	0.99	$74.29
Transfer to Weld Operation	1.45	$108.97
Prep Area & Arrange stainless Strip	0.82	$61.86
Fit-up Sections	4.11	$307.93
GMAW Tack Weld Sections	0.47	$34.91
GMAW First Pass	4.13	$322.41
Flip Module	0.47	$35.43
Back Grind Top of Root pass	1.87	$140.25
Spot PT Root pass	1.03	$77.43
GMAW Second Pass	4.13	$322.41
GMAW Third Pass	4.13	$322.41
Total	23.6	$1,808.30

HDGMAW	Labor Hrs/Unit	Cost/Unit	Comments
HDGMAW flow path			
CNC Plasma Cut Section	0.99	$74.29	Same as baseline
Bevel Edges	1.01	$75.44	New step
Transfer to Weld Operation	1.45	$108.97	Same as baseline
Prep & install Backing bar	1.2	$90.21	1.5 times baseline
Fit-up Sections	6.16	$461.89	1.5 times baseline
GMAW Tack Weld Sections	0.47	$34.91	Same as baseline
HDGMAW Pass	5.16	$406.80	Based on Alcoa data
Flip Module	0.47	$35.43	Same as baseline
Grind/smooth Edges of Root	1.87	$140.25	Same as Back Grind step in Baseline
Total	18.78	$1,428.19	





21% Savings for HDGMAW vs. GMAW Process

LIGHTER. FASTER. STRONGER 5

Figure A17-5 – Detail Cost Analysis Results for Welding Panel to Panel in a Module – Semi—Automated with Moggy Carriage

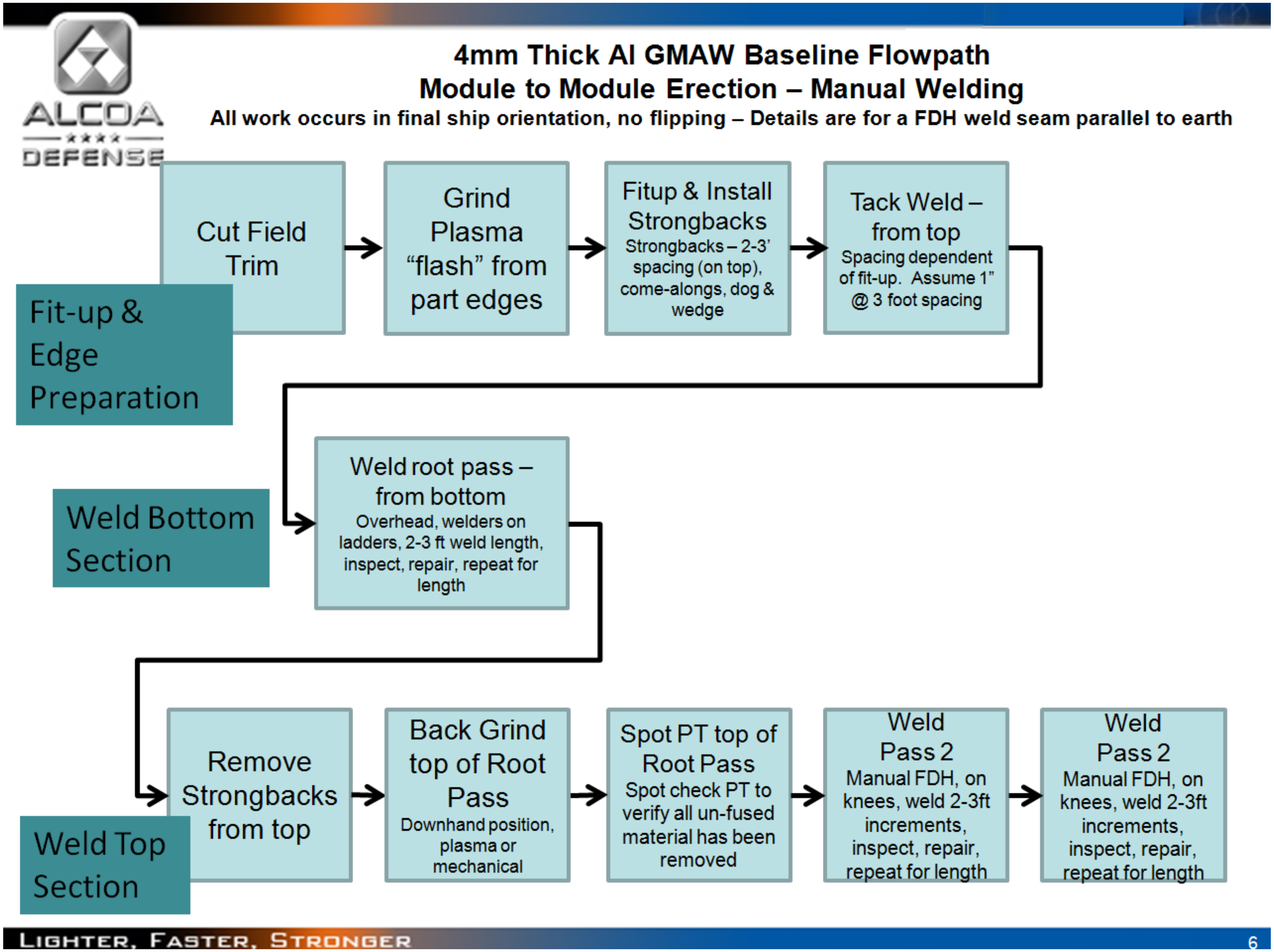


Figure A17-6 – 4mm Thick Al GMAW Baseline Flowpath
Module to Module Erection – Manual Welding

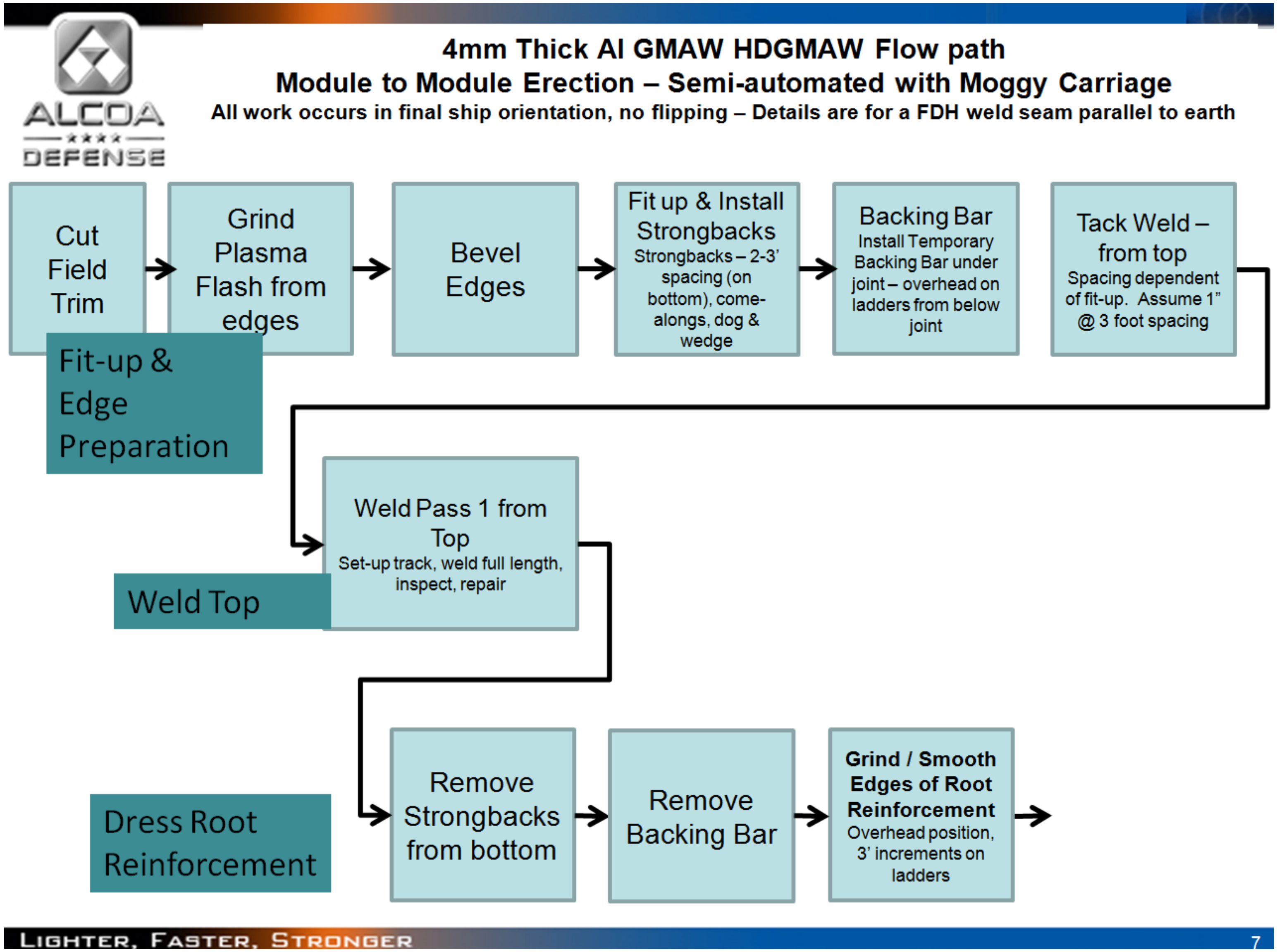


Figure A17-7 – 4mm Thick Al GMAW HDGMAW Flow path
Module to Module Erection – Semi-automated with Moggy Carriage

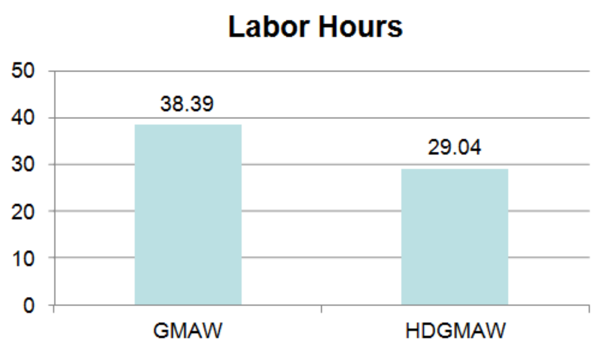
ALCOA DEFENSE

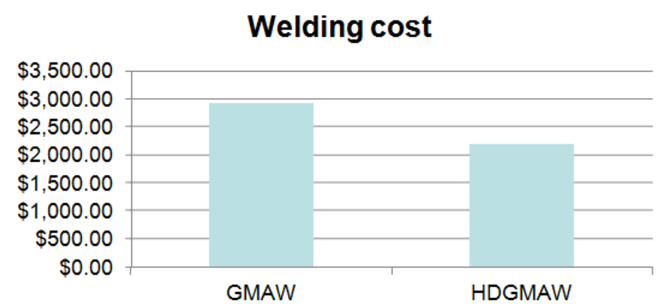
Detail Cost Analysis Results for Welding two Modules
GMAW Manual Weld vs. HDGMAW Semi-automated with Moggy

Vertical Weld, Total Weld Length :40 ft.

GMAW (Baseline)		
	Labor Hrs/Unit	Cost/Unit
Cut Field Trim	1.6	$122.42
Grind Plasma Flash	1.1	$84.68
Fit up and install Strongbacks	3.4	$256.80
GMAW Tack Weld Sections	1.2	$89.13
GMAW First Pass	9.1	$695.26
Remove Strongbcaks & Back grind top of root pass	2.4	$178.88
Spot PT Root pass	1.2	$93.00
GMAW Second Pass	9.1	$695.26
GMAW Third Pass	9.1	$695.26
Total	38.4	$2,910.69

HDGMAW			
	Labor Hrs/Unit	Cost/Unit	Comments
Cut Field Trim	1.6	$122.42	Same as baseline
Grind Plasma Flash	1.1	$84.68	Same as baseline
Bevel Edges	2.06	$154.47	New step
Fit up and install Strongbacks	5.14	$385.21	1.5 times baseline
Install Backing Bar	1.85	$138.58	New step
GMAW Tack Weld Sections	1.2	$89.13	Same as baseline
HDGMAW Pass	12.21	$931.65	Based on Alcoa data
Remove strongbacks & Grind/smooth root	2.4	$178.88	Same as baseline
Remove Backing Bar	1.44	$107.78	New step
Total	29.0	$2,192.80	





24.7 % Savings for HDGMAW Vs. GMAW Process

LIGHTER, FASTER, STRONGER 8

Figure A17-8 – Detail Cost Analysis Results for Welding two Modules GMAW Manual Weld vs. HDGMAW Semi-automated with Moggy

ALCOA DEFENSE

Cost Modeling Results – GMAW vs. HDGMAW – All Welds – Complete Structure

					GMAW			HDGMAW			
Item 1	Item 2	Note	Weld Postion	Total Weld Length (ft)	Labor Hours	Welding Cost	$/ft.	Labor Hours	Welding cost	$/ft.	% Difference
M2	M4	Weld between FSW Decks	FDH	49.5	23.6	$1,808	$36.50	18.8	$1,428	$28.83	21.0%
M1	M3	Weld between FSW Decks	FDH	44.6	21.6	$1,656	$37.11	16.9	$1,283	$28.77	22.5%
M2	M4	Weld between External Bulkheads	Vertical	20.0	20.8	$1,574	$78.68	17.8	$1,342	$67.10	14.7%
M1	M3	Weld between External Bulkheads	Vertical	20.0	20.8	$1,574	$78.68	17.8	$1,342	$67.10	14.7%
M5		Weld between FSW Decks (Deck #1)	FDH	49.5	23.6	$1,808	$36.50	18.8	$1,428	$28.83	21.0%
M6		Weld between FSW Decks (Deck #1)	FDH	49.5	23.6	$1,808	$36.50	18.8	$1,428	$28.83	21.0%
M6		Shell Seam	FDH	44.6	21.6	$1,656	$37.11	16.9	$1,283	$28.77	22.5%
M7		Weld between FSW Decks (Deck #2)	FDH	40.0	20.1	$1,541	$38.50	16.3	$1,238	$30.94	19.6%
M8		Upper to Lower External Bulkhead - Longitudinal	Horizontal	91.9	71.6	$5,439	$59.21	55.3	$4,186	$45.57	23.0%
M8		Upper to Lower External Bulkhead - Transverse	Horizontal	49.5	41.0	$3,111	$62.81	30.6	$2,316	$46.75	25.6%
M9		Upper to Lower External Bulkhead - Longitudinal	Horizontal	82.7	65.0	$4,907	$59.36	50.7	$3,835	$46.38	21.9%
M8	M9	Weld between FSW Decks (Deck #1's)	FDH	49.5	33.3	$2,539	$51.25	26.6	$2,007	$40.52	20.9%
M8	M9	Weld between FSW Decks (Deck #2's)	FDH	44.6	30.3	$2,305	$51.67	23.9	$1,812	$40.62	21.4%
M10	M11	Weld between FSW Decks (Deck #1's)	FDH	49.5	33.3	$2,539	$51.25	26.6	$2,007	$40.52	20.9%
M9	M6	Weld between FSW Decks (Deck #2's)	FDH	44.6	30.3	$2,305	$51.67	23.9	$1,812	$40.62	21.4%
M11	M12	Weld between FSW Decks (Deck #1's)	FDH	49.5	33.3	$2,539	$51.25	26.6	$2,007	$40.52	20.9%
M12	M13	Weld between FSW Decks (Deck #2's)	FDH	44.6	30.3	$2,305	$51.67	23.9	$1,812	$40.62	21.4%
M8	M10	Upper to Lower Ext BHD - Longitudinal	Horizontal	45.9	37.1	$2,816	$61.31	29.1	$2,219	$48.30	21.2%
M9	M11	Upper to Lower Ext BHD - Longitudinal	Horizontal	82.7	65.0	$4,907	$59.36	50.7	$3,835	$46.38	21.9%
M6	M12	Upper to Lower Ext BHD - Longitudinal	Horizontal	82.7	65.0	$4,907	$59.36	50.7	$3,835	$46.38	21.9%
M8	M9	Weld between External Bulkheads	Vertical	40.0	38.4	$2,911	$72.77	29.0	$2,193	$54.82	24.7%
M9	M6	Weld between External Bulkheads	Vertical	40.0	38.4	$2,911	$72.77	29.0	$2,193	$54.82	24.7%
M6	M13	Weld between External Bulkheads	Vertical	40.0	38.4	$2,911	$72.77	29.0	$2,193	$54.82	24.7%
			Total	1155.7	826.3	$62,779	$54.32	647.8	$49,037	$42.43	21.9%

Avg. cost savings of 21.9 % for HDGMAW process

$13,700 savings per ship with 1155 ft. of weld identified as potential application for HDGMAW

LIGHTER, FASTER, STRONGER 9

Figure A17-9 – Cost Modeling Results – GMAW vs. HDGMAW – All Welds – Complete Structure

Cost Modeling Results - GMAW Vs. HDGMAW for FDH Welds – Complete Structure

ALCOA DEFENSE

					GMAW			HDGMAW			
Item 1	Item 2	Note	Weld Postion	Total Weld Length (ft)	Labor Hours	Welding Cost	$/ft.	Labor Hours	Welding Cost	$/ft.	% Difference
M2	M4	Weld between FSW Decks	FDH	49.5	23.6	$1,808	$36.50	18.8	$1,428	$28.83	21.0%
M1	M3	Weld between FSW Decks	FDH	44.6	21.6	$1,656	$37.11	16.9	$1,283	$28.77	22.5%
M5		Weld between FSW Decks (Deck #1)	FDH	49.5	23.6	$1,808	$36.50	18.8	$1,428	$28.83	21.0%
M6		Weld between FSW Decks (Deck #1)	FDH	49.5	23.6	$1,808	$36.50	18.8	$1,428	$28.83	21.0%
M6		Shell Seam	FDH	44.6	21.6	$1,656	$37.11	16.9	$1,283	$28.77	22.5%
M7		Weld between FSW Decks (Deck #2)	FDH	40.0	20.1	$1,541	$38.50	15.7	$1,196	$29.88	22.4%
M8	M9	Weld between FSW Decks (Deck #1's)	FDH	49.5	33.34	$2,539	$51.25	24.16	$1,823	$36.79	28.2%
M8	M9	Weld between FSW Decks (Deck #2's)	FDH	44.6	30.28	$2,305	$51.67	21.88	$1,658	$37.17	28.1%
M10	M11	Weld between FSW Decks (Deck #1's)	FDH	49.5	33.34	$2,539	$51.25	24.16	$1,823	$36.79	28.2%
M9	M6	Weld between FSW Decks (Deck #2's)	FDH	44.6	30.28	$2,305	$51.67	21.88	$1,658	$37.17	28.1%
M11	M12	Weld between FSW Decks (Deck #1's)	FDH	49.5	33.34	$2,539	$51.25	24.16	$1,823	$36.79	28.2%
M12	D4S	Weld between FSW Decks (Deck #2's)	FDH	44.6	30.28	$2,305	$51.67	21.88	$1,658	$37.17	28.1%

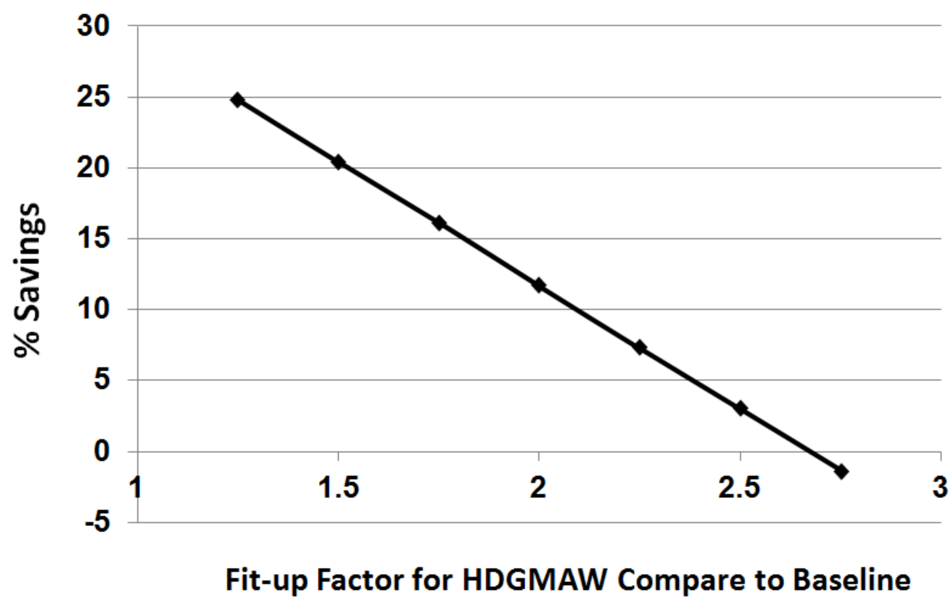
Avg. cost savings 25.5 % for FDH (Flat Down Hold) welds using HDGMAW process
$6,320 savings for 560 ft. of FHD weld identified for HDGMAW

LIGHTER, FASTER, STRONGER 10

Figure A17-10 – Cost Modeling Results – GMAW vs. HDGMAW for FDH Welds – Complete Structure

ALCOA DEFENSE

Sensitivity Analysis for Fit-Up Labor- FDH Weld



Savings for HDGMAW process reduces to zero if labor required for Fit-up for HDGMAW is ~2.6 times Baseline GMAW process

LIGHTER, FASTER, STRONGER 11

Figure A17-11 – Sensitivity Analysis for Fit-Up Labor – FDH Weld

Conclusion

- Cost analysis results indicate average savings of 21.9% for HDGMAW process compare to baseline GMAW for defined flow paths considering 1,155 ft. of weld identified to be potential application of the HDGMAW technology. The cost savings in this case is estimated to be $13,700.
- If HDGMAG technology is applied to only Flat Down Hold (FDH) weld then average cost savings is estimated to be 21.4% & $5,300 for 560 ft. of total FDH weld identified for the complete structure.
- If the Fit-up labor required for HDGMAG higher than ~2.6 times baseline GMAW process (as compare to 1.5 times assumed in the analysis) then welding cost of both process is estimated to be similar.

LIGHTER. FASTER. STRONGER 12

Figure A17-12 – Conclusion

Appendix 18
Go/No-Go Checklist

Parameter or Performance Requirement	Target Metric	Demonstrated Performance	Pass / Fail	Comments
June 2012 Quality Document Weld Parameters				
Top face reinforcement height	<0.090 inch	WPQR passed this requirement, but, expected performance is 0.090 – 0.110 inch	☐ Pass ☒ Fail	Post weld grinding required if this limit is in procurement specification
Reentrant angle at the top weld reinforcement	>90°	30°	☒ Pass ☐ Fail	
Root surface concavity	None Allowed	None Observed	☒ Pass ☐ Fail	
Root surface convexity	<0.090 inch	0.050 inch	☒ Pass ☐ Fail	
Reentrant angle at root reinforcement	>90°	60° - 90° prior to grinding, post weld grind to meet limit	☒ Pass ☐ Fail	Requirement met by post weld grinding
Thickness of welds at top and root	Sufficient to allow grinding an angle >115° for fatigue sensitive Class1 welds	Face & root always convex	☒ Pass ☐ Fail	
Undercut	0.030 inch max or 10% of min. thickness, whichever is less	None Observed	☒ Pass ☐ Fail	
Burn through	None Allowed	None Observed	☒ Pass ☐ Fail	
Incomplete fusion	None Allowed	None Observed	☒ Pass ☐ Fail	
Heat checks	None Allowed	None Observed	☒ Pass ☐ Fail	
Incomplete penetration	None Allowed	None Observed	☒ Pass ☐ Fail	
Cold shut	None Allowed	None Observed	☒ Pass ☐ Fail	
Internal weld cracks	None Allowed	None Observed	☒ Pass ☐ Fail	
Surface breaking cracks	None Allowed	None Observed	☒ Pass ☐ Fail	

Appendix 18 (cont'd)

Parameter or Performance Requirement	Target Metric	Demonstrated Performance	Pass / Fail	Comments
Weld termination	Crack free with the crater pit above the top surface of the part or not on part via runoff tab	Run off tabs used for weld termination	☒ Pass ☐ Fail	
Weld spatter	Less than 0.125 inch in dia. or length; none in UT, PR, or RT inspection areas	Process yields minimum spatter	☒ Pass ☐ Fail	
Weld porosity	As specified in Mil-STD-2035A, 15May1995, Section 5.2.4.4 for RT inspection	<0.1 % T/inch per 6 inches T = Thickness = 5/16 inch	☒ Pass ☐ Fail	Limit is 1 % T/inch per 6 inches
Other Weld Metrics				
Internal weld porosity	< 10%	1%	☒ Pass ☐ Fail	From one representative cross-section
Weld porosity reduction with respect to current GMAW welding for same joint	> 30%	90% reduction	☒ Pass ☐ Fail	Observed on one set of representative cross-sections
Face and root bend tests	Meets AWS B4.0:2007	No discontinuities noted Wraparound Guided Bend Bending Mandrel Diameter – 52.3mm (2.06 in.) (6.66t = 13% elongation)	☒ Pass ☐ Fail	
Weld mechanical strength	Ultimate tensile minimum targets met	UTSmin = 39.9ksi vs. 40ksi limit on WPRQ	☐ Pass ☒ Fail	
Naval Vessel Rules for LCS1 and LCS2	Meet all rules	Not assessed prior to program termination	☐ Pass ☐ Fail	No known other rules that apply
G66 Corrosion Test	Comparable to manual GMAW	No exfoliation corrosion, Pass with PA Rating, No evidence of Preferential Corrosion in the HAZ	☒ Pass ☐ Fail	

Appendix 18 (cont'd)

Parameter or Performance Requirement	Target Metric	Demonstrated Performance	Pass / Fail	Comments
G66 Corrosion after 7 days at 100° C	Comparable to manual GMAW	No exfoliation corrosion, Pass with PB Rating, No evidence of Preferential Corrosion in the HAZ	☒ Pass ☐ Fail	
Metallography and etching of HAZ for beta phase	Comparable to manual GMAW	Not completed prior to program termination	☐ Pass ☐ Fail	
Hardness profile across weld to base metal	Comparable to manual GMAW	Not completed prior to program termination	☐ Pass ☐ Fail	
Fatigue performance	Comparable to manual GMAW	NAVSEA delayed this requirement until Phase II of the program	☐ Pass ☐ Fail	
Minimum Allowable Plate Misalignment for Specified System Performance				
Joint Gap	1.5 mm	2.0mm	☒ Pass ☐ Fail	
Offset	1.5 mm	2.0mm	☒ Pass ☐ Fail	
Joint Gap & Offset (Concurrent)	1.5 mm & 1.5mm	1.5mm gap, 1.0 Offset	☐ Pass ☒ Fail	
Capital and Operating Costs				
Capital cost projection for flat down hand welding system	<$70,000	Not completed prior to program termination	☐ Pass ☐ Fail	
Capital cost projection for horizontal out of position welding system	<$125,000	Not completed prior to program termination	☐ Pass ☐ Fail	
Projected total pro-duction cost reduction for flat down hand welding compared to current baseline welding practices	15% threshold; 30% target	Potential 25.5% savings if fit-up cost for HDGMAW is 1.5X that of Baseline GMAW. Breakeven @ 2.6X.	☐ Pass ☒ Fail	Shipyard input is that cost of insuring fit-up requirements is higher than 2.6X Baseline GMAW

Appendix 18 (cont'd)

Parameter or Performance Requirement	Target Metric	Demonstrated Performance	Pass / Fail	Comments
Specification for Phase 2 Equipment System	Specification complete	Not completed prior to program termination	☐ Pass ☐ Fail	
System Integrator(s) Identified	At least 1 system integrator capable of supporting Phase 2 Development	Four candidates identified	☒ Pass ☐ Fail	
Weld Procedure Specification developed for 8 mm plate based on the other relevant weld requirements contained in this document	WPS completed during Phase 1	WPS Completed	☒ Pass ☐ Fail	
Weld Procedure Qualification Record developed for 8 mm plate based on the other relevant weld requirements contained in this document	WPQR completed during Phase 1	WPQR Completed with the following items not meeting requirements: UTSmin = 39.9ksi vs. 40 ksi limit	☐ Pass ☒ Fail	
Horizontal Out of Position Welding Evaluated	Assessment of Horizontal OOP welding complete	Horizontal OOP welding considered feasible. Some porosity shown & needs to be quantified. Gap & Mismatch tolerance similar to HDGMAW in the FDH Position.	☒ Pass ☐ Fail	
Weld Induced Plate Distortion	Comparable to manual GMAW	Lateral shrinkage reduced by 2.4X & Out of plane distortion reduced by 4.5X	☒ Pass ☐ Fail	

Appendix 19 – Project Risk Assessment

Project Risk Assessment

Title: High Productivity Aluminum Manufacturing (S2404)					
Project Category: Process Change Required with Capital Equip & PO/TWH Approval Req'd					
Status (Pending, Active, Completed):	Active	Active	Active	Active	Completed
Presentation Date:	*5/16/2012*	*10/17/2012*	4/25/2013	MM/DD/YYYY	MM/DD/YYYY
Risk Factors					
1. Project Technical Risk					
2. Design Change Req'd					
3. Program Office/TWH Approval Req'd					
4. Major Milestone or Go/No Go Decision Req'd					
5. Product / Process Certification Req'd					
6. Capital Equipment Funding Req'd (Austal)					
6. Capital Equipment Funding Req'd (MMC)					
7. Outside Implementation Funding Req'd (Austal)					
7. Outside Implementation Funding Req'd (MMC)					
8. Business Case Strength / Benefit (Austal)					
8. Business Case Strength / Benefit (MMC)					
9. Insertion Schedule (Shipbuilding / AC Schedule)					
10.Technology / Product Maturity					
11. Commercialization Partner Req'd					
OVERALL ASSESSMENT OF RISK					

Note: ONR evaluation shown for IPT presentation dates of 5/16/12 and 10/17/12.

Green	Implementation risks are minimal and/or risks have been adequately addressed
Yellow	Potential issue / meeting implementation requirements uncertain
Red	Currently an issue / doesn't meet requirements for implementation

Appendix 19 (cont'd)

Project Risk Assessment Details

1. Technical Risk (Yellow to Red) – Welding with seam tracking and plate gaps of 1.5mm and offsets of 1.0mm (simultaneous) demonstrated. However, this may not be large enough for shipyard use. Implementation of temporary backing bar also a concern, especially in module erection. Some welds may not be candidates for the process due to space limitations for the equipment. Root reinforcement grinding is a concern, especially in module erection.

3. Program Office / TWH Approval Required (Yellow) – TWH/PO have been briefed and support project. ABS and NAVSEA 05 are part of the team and support project.

5. Certification Required (Red) – Per NAVSEA/ABS, certification requirements for high deposition gas metal arc welding will be the same as for conventional GMAW. Additional Navy certification requirements provided by Cathy Wong have been integrated into the Go-NoGo Phase 1 checklist. High percentage of tests are complete, but, some are on hold. Ultimate Tensile Strength and Face Reinforcement limits are not met and need NAVESEA approval.

Project Risk Assessment Details Cont'd

6. Capital Equipment Funding Required (Red) – Both Austal and Marinette are aware of the estimated capital equipment costs through their work on the Technology Transition Plan. To move this risk to yellow, the actual capital funding request has to be created and routing for approval. This won't occur until the final equipment system has been defined. Per the project plan, this won't occur until April 2014.

7. Outside Funding Implementation Required (Red) – Estimates for additional expenses to implement technology have been made by Austal and Marinette and documented in the Technology Transition Plan. Anticipated additional funding requirements for final implementation have been identified in the TTP. Until actual system requirements are known (in the April 2014 timeframe), and the funding request is made and under consideration, this risk cannot move to yellow.

Project Risk Assessment Details Cont'd

8. Business Case Strength/Benefit (Red) – Phase I Business Case update is on hold. Expect ROI to decrease from proposal Business Case due to lower applicable weld length than in Proposal Business Case, cost of implementing Temporary Backing Bar – especially in Module Erection Welds, Feasibility/Additional Costs to maintain gap/vertical mismatch within limits demonstrated in Phase I, need to grind root reinforcement to meet re-entrant angle requirement. Full benefit is dependent on Out of Position Welding, including vertical up of out-of-position which is currently unknown.

10. Technology/Product Maturity (Yellow) – Successfully demonstrated in the lab at 8mm initial program thickness. The general capability of HDGMAW has been established. Per the first risk, additional technology development during planned program tasks is needed to ensure desired capability of the final production system is achieved.

11. Commercialization Required (Red) – Commercialization partner has not been identified; will occur in Phase II.

Project Categories - Definitions

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Project categories in descending order of historical implementation success and, therefore, desirability

1. **Process Change under Cognizance of Industry**
   - A production **process change** that does not impact the fit, form, or function of a platform component and does not require formal Navy approval. Production Processing Change, Production Material Change and Above-the-Shop Floor Production Engineering/Planning Improvement are all examples that fall under this project category. The process should require only technical equivalency, technical maturity, and a strong business case to meet implementation requirements.
2. **Process Change Requiring PO/TWH Approval**
   - A production **process change** that impacts the fit, form, or function of a platform component. A Production Processing Change and Production Material Change associated with a Navy-controlled specification can fall under this project category. An example project is a new welding process. The approval of the new process requires **formal written approval by the PO/TWH** for implementation.
3. **Process Change Requiring Capital Equipment**
   - A production **process change** that does not impact the fit, form, or function of a shipboard component and does not require formal Navy approval. However, the **solution requires capital investment** by the implementing organization. Production Processing Change, Production Material Change and Above-the-Shop Floor Production Engineering/Planning Improvement are types of projects that fall under this project category. Capital investment should be over $50K to be considered in this category.
4. **Process Change Requiring Capital Equipment and PO/TWH Approval**
   - A production **process change** that impacts the fit, form, or function of a shipboard component but also requires capital investment by the implementing site. The approval of the new process requires formal written approval by the PO/TWH for implementation. Production Processing Change and Production Material Change associated with a Navy-controlled specification are types of projects that fall under this project category. This capital investment decision adds to the difficulty of implementation path and adds uncertainty to future implementation.
5. **Design Change Requiring PO/TWH Approval**
   - A change to a platform component or structure that has significant collateral impact . Such a change will require significant documented approvals by the Program Office and (sometimes multiple) TWHs and can have impact on logistical systems.
6. **Design Change Requiring PO/TWH Approval and Certification**
   - A change to a platform component or structure that has significant collateral impact . This type of change is characterized by a requirement fo documented approvals by the PO and (sometimes multiple) TWHs after the successful completion of the certification program that could include FEM modeling and simulation to verify performance, or large-scale testing, materials testing, and full-scale trials, for example. These types of ManTech projects are very difficult to transition due to the need for large amount of outside funding required to complete all certification testing.

NAVY MANTECH manufacturing technology program

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Appendix 19 (cont'd)

Risk Factors – Definitions

1. Project Technical Risk
   - This factor measures the risk of achieving the stated technical objectives of the project. Adequate funding, available resources, and technical expertise assigned to the project contribute to this factor. Risks are mitigated by having all project participants and stakeholders agree to these objectives prior to project execution. Further risk mitigation occurs when these agree-upon objectives are clearly state and both interim and final technical objectives are met on or ahead of schedule.
2. Design Change Required
   - A design change is often very difficult to obtain approval for unless the baseline process is found inadequate. A design change may require various levels o approvals and may require an extensive amount of resources and time to implement. This risk factor includes, for example, the degree of added time, resources, and complexity of the design change required for implementation.
3. Program Office/TWH Approval Required
   - A project requiring PO and/or Technical Warrant Holder future (documented) approval adds levels of complexity to the implementation process. This risk factor includes the criticality of the ManTech solution, the amount of resources and time needed to secure the approvals, and the current measure of suppor from these organizations .
4. Major Milestone or Go/No Go Decisions Required
   - ManTech projects often require major milestones or go/no go decisions to be made in order to implement a solution. Significant implementation risks can occur when major milestones occur at the end of a ManTech project or after completion of the project. Additional risk occurs when the major milestone or go/no go decision is the responsibility of a entity outside of the ManTech community.
5. Certification Required
   - When implementing a change to a platform system, the component or material will be subjected to an analysis to determine that the change can meet all platform requirements. This can result in materials testing and evaluation, component prototype fabrication and performance testing, platform trials, etc. In such cases, the time and resources may be extensive. This risk factor includes the time, resources and uncertainty resulting from the need to certify the product or process.
6. Capital Equipment Funding Required
   - It is inherently risky when implementation is dependent on a implementation site's required capital investment to initiate implementation. The severity of this risk is dependent on the amount of the investment, the timing of this investment decision and any current business case analysis data. Input from the company is critical in this factor.
7. Outside Implementation Funding Required
   - Funding required to implement ManTech solution into production (funding not provided by ManTech). It does not include capital equipment, but includes nonrecurring engineering costs, certification or verification testing programs, prototype construction, training, and start-up production costs. Important contributors include whether the funding is secured, planned, or unplanned. The certainty of the commitment to the amount and the identification of the sources are important as well.

NAVY MANTECH manufacturing technology program

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Risk Factors – Definitions (cont)

8. Business Case Strength / Benefit
   - ManTech projects typically complete prior to the customer's making a detailed business case analysis to justify implementation. In order to continue support of ManTech projects, there needs to be some confidence developed that shows that the solution will be found beneficial and subsequently implemented. Strong business case analysis that includes all costs associated with implementation and includes cost engineering estimate of future benefits lessens the risk. Business case benefits that are not updated or revisited or are based on broad and general estimates of labor or material savings increases the perceived risk.
9. Insertion Schedule (Shipbuilding / Aircraft Schedule)
   - Benefits are maximized when applied to a first of a class or early in the class construction. If a project's benefits are significantly impacted by applying a solution to a specific implementation target, then the insertion schedule is important. Once a target implementation is identified, then the ability of the solutio to meet that target must be evaluated. This risk factor tracks the project's ability to meet the target implementation on the specific build of the target platform or weapon system with certainty.
10. Technology / Product Maturity
    - A solution may result in a new product or technology that must be implemented into production or aboard the platform. Sometimes these solutions do not involve mature manufacturing processes or have be utilized extensively in the manner planned for by implementing the project's solution. This category is intended to measure the robustness and reliability of the process or product for the intended application
11. Commercialization Partner Required
    - New components or new processes may require components that have not be previously made before in a commercial industry. This risk factor addresses the potential to commercialize the product or process . Important considerations in this factor include whether a commercial source has been developed anc is capable of meeting the demands that may be required of it once the solution is fully implemented . If cost savings are considered important, then the commercial source must provide some documentation that it can produce the product or process at the cost being used in the business case analysis.

NAVY MANTECH
manufacturing technology program

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Appendix 19 (cont'd)

Project Implementation Risk Assessment / Management
Risk Factors - Expanded Definitions (Mar 2012)

	1	2	3	4	5	6
	PROJECT TECHNICAL RISK	DESIGN CHANGE REQUIRED	PROGRAM OFFICE / TWH APPROVAL	MAJOR MILESTONE OR GO/NO GO DECISIONS REQUIRED	CERTIFICATION REQUIRED	CAPITAL EQUIPMENT FUNDING REQUIRED
Description	This factor measures the risk of achieving the stated technical objectives of the project. Adequate funding, available resources, and technical expertise assigned to the project contribute to success for this factor. Risks are mitigated by having all project participants and stakeholders agree to these objectives prior to project execution. Further risk mitigation occurs when these agreed-upon objectives are clearly stated and both interim and final technical objectives are met on or ahead of schedule.	A design change is normally difficult to have approved unless the baseline process is inadequate. Implementing a design change may require several levels of approvals and an extensive amount of resources and time. This risk factor covers the implementation complications resulting from design dependency inherent in this type of project.	A project requiring future Program Office (PO) and/or Technical Warrant Holder (TWH) approval adds more complexity to the implementation process. This risk factor includes the criticality of the ManTech solution, the amount of resources and time needed to secure the approvals, and the current measure of support from these organizations.	ManTech projects often require major milestones or go/no go decisions to be made in order to implement a solution. Significant implementation risks can occur when major milestones occur at the end of a ManTech project or after completion of the project. Additional risk occurs when the major milestone or go/no go decision is the responsibility of an entity outside of the ManTech community.	When implementing a change to a platform system, the component or material will be subjected to an analysis to determine that the change can meet all platform requirements. This can result in materials testing and evaluation, component prototype fabrication and performance testing, platform trials, etc. In such cases, the time and resources may be extensive. This risk factor includes the time, resources, and uncertainty resulting from the need to certify the product or process.	It is inherently risky when implementation is dependent on an implementation site's capital investment. The severity of this risk depends on the amount, timing and business case status for this investment..
Green	**GREEN** – The project has demonstrated the successful completion of established major technical milestones.	**GREEN** – Design change completed and approved.	**GREEN** – PO/TWH approval letter or e-mail documentation has been received by project team.	**GREEN** – Major milestones are complete and/or Go/No-Go decisions have been positively resolved.	**GREEN** – Certification required for project implementation has been achieved.	**GREEN** – Plan to purchase capital equipment necessary for implementation has been approved and budgeted **OR**. Capital equipment procurement is complete or in process.
Yellow	**YELLOW** – TTP has been signed by all parties. **AND**. The project has established major technical milestones but has not completed all scheduled milestones and project fully accounts for all resources needed to complete technical tasks.	**YELLOW** – Design change-related costs are well-defined, known by the PO, and budgeted. **OR**. Design change will result in no or minimal nonrecurring engineering cost, transition cost, and implementation cost and no impact to the construction schedule.	**YELLOW** – PO/TWH has been briefed and supports project but unwilling to document approval via e-mail or in writing until further technical or programmatic questions are answered.	**YELLOW** – Major milestones or Go/No-Go decision in project still pending but current indications are that they will be positive.	**YELLOW** – Certification requirements are approved by appropriate authority; resources required to complete the certification are secured, but data to support certification decision is not yet complete or has not been evaluated by certification authority.	**YELLOW** – Capital equipment funding requests have been generated and management decision is pending. **AND**. Business case is positive for procurement of the equipment.
Red	**RED** – TTP has been developed / routed for approval but has not yet been not approved by participants. **OR**. TTP has been signed but issues have come up since initial signing. OR. Project has failed to achieve at least threshold value in at least one technical requirement.	**RED** – Design change is significant, not well-defined, and/or resources for implementing the design change are not secured. **OR**. PO has not approved plans for the change.	**RED** – PO/TWH has not been fully briefed and is unaware of project. **OR**. PO/TWH has expressed nonsupport of initiative.	**RED** – Failed a major milestone or Go/No-Go decision or project team has negative information in hand that will likely lead to milestone failure when review occurs.	**RED** – Certification requirements are not fully identified and documented or not yet approved by the appropriate authority. **OR**. Certification program requirements are known and involve significant unsecured resources. **OR**. Threshold value required to meet certification requirement not achieved.	**RED** – Detailed request for necessary capital equipment has not been generated. **OR**. Request was submitted and rejected.

Appendix 19 (cont'd)

Project Implementation Risk Assessment / Management
Risk Factors - Expanded Definitions (Mar 2012)

	7	8	9	10	11
	OUTSIDE IMPLEMENTATION FUNDING REQUIRED	BUSINESS CASE STRENGTH / BENEFIT	INSERTION SCHEDULE (SHIPBUILDING / AIRCRAFT SCHEDULE)	TECHNOLOGY / PRODUCT MATURITY	COMMERCIALIZATION PARTNER REQUIRED
Description	Funding required to implement ManTech solution into production (funding not provided by ManTech). It does not include capital equipment, but includes nonrecurring engineering costs, certification or verification testing programs, prototype construction, training, and start-up production costs. Important contributors include whether the funding is secured, planned, or unplanned. The certainty of the commitment to the amount and the identification of the sources are important as well.	A strong business case analysis includes all costs associated with implementation and includes an engineering estimate of future benefits. Risk in this category is increased if business cases are not updated as the project progress or are based on general estimates of labor or material savings and implementation costs.	Benefits are maximized when applied to a first of a class or early in the class construction. If a project's benefits are significantly impacted by applying a solution to a specific implementation target, then the insertion schedule is important. Once a target implementation is identified, then the ability of the solution to meet that target must be evaluated. This risk factor tracks the project's ability to meet the target implementation on the specific build of the target platform or weapon system with certainty.	A ManTech solution may result in a new process or product technology that must be implemented into production or aboard the platform. These solutions may involve immature manufacturing processes or technology that has not been utilized extensively in the manner planned for by the project. This category is intended to measure the robustness and reliability of the process or product as it is developed through the project.	New manufacturing tools or new processes may require components that have not been made before in commercial industry. This risk factor addresses the plan to commercialize the product or process. Important considerations in this factor include whether a commercial source has been developed and is capable of meeting the demands that may be required of it once the solution is fully implemented. If cost savings are considered important, then the commercial source must provide some documentation that it can produce the product or process at the cost being used in the business case analysis.
Green	**GREEN** – Implementation funding requirements are firm and appropriate sources have budgeted needed funds. **OR**. Implementation funding requirements are minimal and not seen as a barrier.	**GREEN** – Business case is fully developed and accepted by the implementing facility. Business case is strong (significant benefit for costs required) and industry plans to implement project results.	**GREEN** - Project success not dependent on meeting specific implementation target date, and results can be implemented when complete. **OR**. Project has firm implementation target date and has met all major milestones to meet required schedule.	**GREEN** – Technology has been matured and tested. Transition issues related to technology maturity are expected to be minor.	**GREEN** - A qualified commercial manufacturing facility is involved in the construction of equipment developed under ManTech effort and has committed to producing the adequate quantities of the end-product at a specific target price.
Yellow	**YELLOW** – Implementation funding requirements are known; funding is not secured but sources have been identified and sources are considering funding request.	**YELLOW** – Business case has been developed and appears to warrant implementation consideration. Industry still evaluating to make implementation decision.	**YELLOW** – Project deliverable is tied to an implementation target, and implementation plan on track to meet target date, but project still has milestones to accomplish before implementation can occur.	**YELLOW** – Plan to test, mature, and prove technology in a relevant environment is complete. **OR**. Alpha or Beta testing underway but not complete or refinements not yet captured.	**YELLOW** – Requirements for a commercialization partner have been defined, and candidates have been identified. The partner has not yet demonstrated the ability or commitment to produce the necessary components at the agreed upon price.
Red	**RED** – Implementation funding is required but requirements are undefined or unknown. **OR**. Implementation funding requirements are known, but no specific source for funding has recognized funding request.	**RED** – Business case is immature or non-existent. **OR**. Business case complete but strength of case is uncertain or benefit may be marginal.	**RED** – Project has an implementation target but has not yet developed plan to meet it. **OR**. Project is time-sensitive and has fallen behind schedule.	**RED** - Technology to be used in project is not fully defined or plan to mature / validate technology is not complete.	**RED** – It is anticipated that a commercialization partner will be needed, but one has not yet been identified to participate in the project.